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Roman L. Hruska U.S. Meat Animal Research Center
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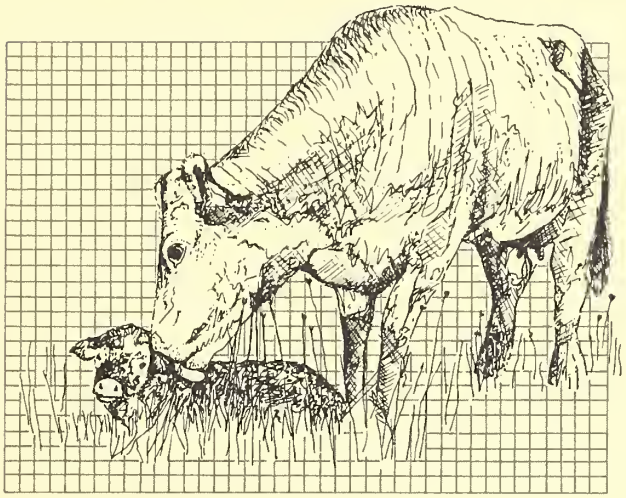

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ROMAN L. HRUSKA U.S. MEAT ANIMAL RESEARCH CENTER[1]

1. **Overview of Center:** The U.S. Meat Animal Research Center (MARC) was authorized by Congress on June 16, 1964, thereby creating a single facility that provides an unusual opportunity for making major contributions to the solution of problems facing the U.S. livestock industry. Development of the 35,000-acre facility started in the spring of 1966 and is continuing at the present time. Phase I construction, consisting of an office-laboratory building for intensive investigations, was completed in January 1971. These facilities provide a physical plant for 42 scientists and about 200 support personnel. Phase II construction, consisting of the Meats Research Laboratory and Agricultural Engineering Building, was completed in October 1977 and provides a physical plant for 25 scientists and about 60 support personnel. Phase III construction will provide facilities for a comprehensive research program of producing, harvesting, handling, storing, and using forages in livestock production systems. Approximately 35 additional scientists and 65 support personnel will be required for this phase. Currently, one-third of the scientific staffing is completed.

Approximately 50 percent of the research program is devoted to beef cattle, 30 percent to swine, and 20 percent to sheep. Current research program objectives require breeding-age female populations of approximately 7,000 cattle (17 breeds), 4,000 sheep (8 breeds), and 600 swine litters (8 breeds) per year.

The research program at the Center is organized on a multidisciplinary basis and is directed toward providing new technology for the U.S. livestock industry by extending investigations into new areas not now being adequately studied. The research program complements research conducted elsewhere by the U.S. Department of Agriculture and is cooperative with the Nebraska Agricultural Experiment Station and other land grant university agricultural experiment stations throughout the country.

On October 10, 1978, the President signed into law a bill renaming the U.S. Meat Animal Research Center the Roman L. Hruska U.S. Meat Animal Research Center. The purpose of the bill was to honor former Nebraska Senator Roman L. Hruska for "his efforts in the establishment of a centralized Federal facility for the research, development, and study of meat animal production in the United States."

[1]Agricultural Research Service, U.S. Department of Agriculture, the University of Nebraska, and other cooperating land grant universities.

2. Overview on the Beef Cattle Research Program: MARC's beef cattle research program places the highest priority on developing technology capable of having an immediate and major impact on the beef cattle industry. Although the program is largely oriented towards fundamental research, emphasis is placed on the generation of technology that can be practically implemented by small farmers and commercial beef cattle producers alike within a relatively short time frame. Because of the uniqueness of the Center's resources, research is being conducted on a "conception to consumption" basis with beef cattle.

Currently, we have 20 scientist "equivalents" conducting research in the beef cattle program at MARC. They are working in 11 primary research thrust areas. In addition, they are coworkers on five major projects away from MARC. Also, MARC has an active postdoctoral and visiting scientist program, which supports the beef cattle research program.

This report represents a cross section of our beef cattle research program at the present time. Since some of the projects from which results are reported are still in progress, the preliminary nature of some of the results must be recognized. However, it is our opinion that information useful to the industry should be provided at the earliest possible time. Progress reports of this nature will be released periodically to make current results available to the industry. For the reader's convenience, the table of contents of this report is organized by disciplinary unit which is taking the lead in each specific problem area. The articles within the body of the report are arranged as they most closely relate in subject matter.

3. Appreciation: I want to express my appreciation to Margie McAlhany, MARC Information Officer, and Gordon Hays, Cattle Operations Manager, for serving as coeditors of this report, I also want to thank Linda Kelly for proofreading the report and Linda Doele for preparation of the final copy. These individuals have contributed many hours to the completion of this report.

Robert R. Oltjen, Director
Roman L. Hruska U.S. Meat
Animal Research Center

Cattle Management at MARC

Margaret S. McAlhany, W. Gordon Hays, and William G. Kvasnicka[1]

The Cattle Operations Unit is designed to function as a support area to the research scientists. The operations personnel maintain the animal populations necessary for our livestock research. Indirectly, this also involves responsible land management and herd health procedures. All the facilities and procedures employed in maintaining the extensive cattle herd are determined by research needs. Consequently, while providing a function sometimes indirectly related to research, the operations unit is necessary to provide adequate feedstuffs and healthy animals for research studies.

Facilities

Cow-Calf Polesheds. There are nine polesheds at MARC employed in maintenance of the 7,000-cow breeding herd. Each area functions as a working area with general-purpose facilities designed for calving, artificial insemination, pregnancy checking, and routine processing of the cattle herd. These facilities generally include a scale, manual chute, calf-pulling stall, and individual pens (ranging from 10 to 25, depending upon use in cow or heifer calving areas). Individual pens are used primarily in the spring during the main calving season and are used either after assistance to the cow or heifer during calving or to provide assistance to the calf in cases of severe chilling, poor mothering, or sickness. Corrals are used for holding or sorting cattle. Each area is equipped with a "hot house," which is a heated office and supply area.

Construction of the polesheds (and other polesheds at the center) makes use of military surplus railroad ties for supports and surplus sheet metal for siding and roofing. Rafters are made of wood, and floors are all dirt except for concrete in office and working areas.

Bull Barn. Construction is similar to cow-calf polesheds. This area is used for routine processing, semen collection, and special research studies. Pens are available for holding and sorting bulls. A heavily constructed squeeze alley and chute are used for processing and semen collection. A special area is designed for libido evaluation. The hot house includes an office and lab for semen evaluation.

Feedlot. Five thousand five hundred calves and assorted other cattle are fed in the feedlot, primarily in the winter. This number includes animals which will be used in the breeding herd, animals which will be fed for slaughter, cows for reproduction studies, and breeding bulls. Performance and puberty studies are routinely conducted on many of the young calves as part of genetics studies. Approximately 80 percent of the calves are born in the spring (3,900) and come to the feedlot averaging 6 months of age in the fall. Twenty percent (800) of the calves from the fall calving herd enter the feedlot at approximately 5 months of age.

Multi-Purpose Building. The main processing facility is a pre-engineered metal building, fully lighted and heated with concrete flooring. The working facility includes a circular squeeze, working alley, scale, and chute. Fifteen pens are used for sorting and holding. There is also an office and lab area. A reproductive physiology lab is a separate, thermally controlled area specifically designed for embryo transfer and other cattle physiology research.

Scalehouse. This is a pre-engineered metal building which functions as the main doctoring area and as office headquarters for the feed-truck drivers. A working alley, scale, and chute are included in this area, as well as sorting pens and sick pens.

Poleshed. This barn functions as a sale and physiology facility. It includes a working alley and chute. There is a heated office and a sale ring. Holding pens are used predominantly for embryo transfer donor cows.

Cattle Confinement Area. There are 11 pre-engineered metal buildings in this area. Total animal capacity is 1,500 head. It functions mainly as an area for intensive nutrition or reproduction research.

One building is designed for research as a cattle surgery facility. This building includes a prep room, surgery room, recovery stalls, lab, and office.

Four barns are equipped with individual headgates for intensive feeding studies. Two of these are designed to accommodate cows with calves and have been used predominantly for cow efficiency studies. The other two are used for post-weaning experiments requiring individual feed consumption data.

A specially designed barn includes 12 metabolism crates used to study animal utilization of nutrients. In addition, thirty-six stalls equipped with headgates are primarily used for studies requiring the frequent collection of blood samples for hormonal determinations. Three calorimeters are used for fasting heat production studies. A nursery has been developed for artificial rearing of calves for specific research studies. The barn also contains a lab.

Two buildings are equipped with self-cleaning pens with a flushing gutter and are used for total confinement research. Working facilities include an office, lab, crowding area, working alley, scale, chute, and sorting pens.

Laboratory Complex. Of the four buildings in the main office and laboratory complex, two are used frequently for beef cattle studies. The meats complex contains an abattoir and a sensory evaluation area (taste panel) which are used extensively for carcass evaluation studies. The ag engineering unit has an animal laboratory area equipped with environmental chambers. These chambers can be adapted for any of the animal species studied at MARC, but cattle studies have focused on the effect of the thermal environment (temperature and humidity in particular) on the performance of feedlot and breeding cattle.

Necropsy Building. This building is equipped with a dissection room, holding cooler, lab, and office area. It is used by MARC veterinary staff to autopsy any animals that die and to determine the cause of death. This is a routine procedure to monitor any changes that might occur with regard to herd health status.

Land Management

The land is managed so that 27,000 acres of land — (warm- and cool-season grasses) are used as pastures. Twenty-five thousand acres are used for pastures for the cattle herd. Cows are maintained on pastures year-round and supplemented with hay in the winter. Heifers are supplemented with a haylage-corn silage diet through their first calving. Bulls are on pastures during the summer and are primarily maintained in the feedlot during the winter.

Six thousand acres of land are irrigated for crops and hay production. The two main feedstuffs produced at MARC are alfalfa (2,300 acres) and corn (3,000 acres). The first cutting of alfalfa is chopped for haylage and subsequent cuttings harvested for hay. Corn acreage yields an annual 35,000 tons of silage and 200,000 bushels of corn. (All feedstuffs are used for both the sheep flock and the beef herd. Corn is also a major component of the swine diet.) Additional acreage includes irrigated pasture and small grains used for forage and feed.

[1]McAlhany is the information officer, MARC; Hays is the cattle operations manager, MARC; and Kvasnicka is an extension veterinarian for the State of Nevada (formerly herd health veterinarian, MARC).

General Management Practices

The cow herd is managed so that 80 percent of the cows and heifers (4,200 head) will calve during the spring calving season (March through May). Another 1,000 head will calve during the fall season (August through early October). Calf survival each year ranges from 92 to 93 percent.

First-calf heifers are managed to start calving two weeks ahead of the cows, so the breeding season begins the end of May for heifers. They are bred during a 45-day mating season with yearling bulls. The breeding season for cows starts with 30 days of artificial insemination and ends with a 30-day natural mating period. Average conception rate, combining heifers and cows, is 88 percent.

A very young cow herd is maintained to meet research objectives. Approximately 40 percent of the breeding herd is composed of yearlings and two-year-old cows. Many prime-aged (three- to six-year-old) pregnant cows are merchandised each year in a bred cow sale. Excess breeding bulls are also sold in this manner.

Herd Health Procedures

The following are the vaccination and routine processing procedures for heifers, cows, calves, and bulls.

Heifers. Prior to their first breeding season, yearling heifers are injected with killed BVD-IBR-PI3 (bovine respiratory disease-infectious bovine rhinotracheitis-parainfluenza), 5-way leptospirosis, vibriosis in oil, 7-way blackleg, and Haemophilus vaccines. Approximately 70 days after the end of breeding season, heifers are palpated for pregnancy, injected with ivermectin for parasite control, and vaccinated against *E. coli* bacteria. Prior to calving, brands are clipped, and heifers are given *E. coli,* 7-way blackleg, and vitamins A and D.

Cows. After calving and before breeding, cows are given the same injections as heifers. At 70 days postbreeding, they are pregnancy checked and treated for external and internal parasites. Prior to calving, they receive the same treatment as heifers. They are also culled after pregnancy detection if they fail to conceive or are no longer needed for research needs.

Calves from Birth to Maturity. At birth, all calves are dehorned (paste) and vaccinated against viral scours, and the navel is treated with iodine. Depending upon research projects, some calves may be castrated. Prior to the cow breeding season, the calves are vaccinated with 4-way blackleg and 5-way leptospirosis. Three weeks preweaning, calves are preconditioned with a parasite control agent and are vaccinated with killed BVD-IBR-PI3, 4-way blackleg, 5-way leptospirosis, and Haemophilus. This year one-half of the calves are also being vaccinated with an experimental serum for bovine respiratory syncytial virus (BRSV) when preconditioned and again at weaning. At weaning time, they are vaccinated a second time with killed BVD-IBR-PI3 and Haemophilus. One month postweaning, brucellosis vaccine is given to heifers. At one year of age, some of the bulls and heifers enter the breeding herd. Some of the bulls are sold as breeding stock, and the rest of the heifers, bulls, and steers are either used for research studies or are fattened for slaughter.

Bulls. At the end of the growing period (one year), bulls are vaccinated with killed BVD-IPR-PI3, 4-way blackleg, and 5-way leptospirosis. Subsequently, they are treated for parasites and vaccinated with 5-way leptospirosis prior to each breeding season.

Genetic Relationships Among Carcass Traits and Their Implications in Selection Programs

Robert M. Koch, Keith E. Gregory, and Larry V. Cundiff[1,2]

Introduction

Two alternatives for breeders to match cattle resources with other production resources and market requirements are (1) identify a breed that is a good fit for the production requirements or (2) use systematic crossing of breeds that will complement each other most effectively to provide for the most profitable combination of characteristics. In either alternative, selection within breeds can be used to change the genetic values of specific traits to increase adaptability to the production system. The study reported here evaluates the genetic relationships among growth and carcass traits and assesses responses expected from selection.

Procedure

Data from 2,453 steers were analyzed. The steers were part of the germ plasm evaluation (GPE) program at MARC. Samples of steers from each breed-of-sire group were slaughtered at a commercial packing plant. One side of each carcass was transported to Kansas State University for detailed evaluation. The side was separated into wholesale cuts and processed into closely trimmed, boneless retail cuts, except that a small amount of bone was left in short loins and in rib cuts. No more than .3 inch of fat was left on the surface of retail cuts. Lean trim for ground beef from all wholesale cuts was trimmed to contain 25 percent fat. Retail product in this study was the sum of roast and steak meat and lean trim. Fat trim was the sum of fat trim from cuts and the kidney and pelvic fat (kidney included).

Results

Overall means, heritabilities, and genetic and phenotypic correlations are presented in Table 1. *Heritability* is the fraction of the observed differences between animals caused by average genetic differences. *Genetic correlations* measure the average genetic association between traits. *Phenotypic correlations* measure the total association (genetic + environmental) between traits.

Estimates of heritability from this study were in reasonable agreement with the average from other studies except for gain from birth to weaning, which was distinctly lower (.07 *vs* .30) and feedlot gain, which was higher (.57 *vs* .34). It is possible that the Hereford and Angus cows used in this study may have restricted the genetic potential of growth of their calves to weaning, which was compensated for under the *ad libitum* postweaning feeding conditions.

Predicted response to selection for feedlot gain, side weight, retail product percentage, or decreased fat thickness. Correlated responses to selection for feedlot gain (criterion 1 in Table 2) were essentially the same as response to selection for side weight (criterion 2 in Table 2) because the heritability of feedlot gain was higher than side weight (.57 *vs* .43), and the genetic correlation between them was high (.89). Selection for increased growth rate through greater daily gain in the feedlot or side weight resulted in sizable increases in weight of retail product, fat trim, and bone. Although retail product represented the largest fraction of the increase in side weight, the net change in composition produced a decline in retail product and bone percentages on an age constant basis. When compared at a constant side weight, retail product and bone percentages increased and fat trim percentage decreased. Maturity differences associated with composition are maximized in contrasts at a constant carcass weight. These results suggest that selection for increased growth rate would lead to leaner, later maturing types.

Selection for retail product percentage (criterion 3 in Table 2) would cause relatively little change in side weight, increase weight and percentage of retail product and bone, and decrease weight and percentage of fat trim and marbling.

Although it is not possible with current technology to assess retail product weight or percentage directly, the measurement of fat thickness in the live animal by probe or ultrasound techniques provides a viable alternative for changing carcass composition by selection. There may be some practical limitations in obtaining accurate measures of fat thickness on bulls and heifers because the variation in fat thickness among animals in breeding condition is much less than among steers fattened for market. Selection for reduced fat thickness (criterion 4 in Table 2) would not alter side weight appreciably, but would increase the percentages of retail product and bone and decrease fat trim. On a weight constant basis, selection for reduced fatness would lead to greater changes in retail product percentage than selection for feedlot gain or side weight, but about 40 percent less change than expected if selection could be based directly on retail product percentage.

Response in fat thickness followed the pattern of response in fat trim percentage, and response in rib eye area followed the pattern of response in retail product percentage because of their high genetic correlations with these traits.

Selection criteria that increased retail product percentage also decreased marbling score. The expected decrease in marbling score was small when selection was for feedlot gain or side weight.

Genetic increases in growth rate favor growth of lean tissue relative to fat. Environmental increases in growth rate, such as increased energy intake, favor growth of fat tissue relative to lean. Expected responses to selection for rate of gain are increased market weight and retail product, but less fat (at a constant weight) and an increase in mature size in the cow herd. Expected responses to selection for decreased external fat thickness are increased weight and percentage of retail product, but no change in market weight or mature size of cows. Equal selection emphasis for rate of gain and fat thickness reduces the expected increase in market weight and mature size, and the net increase in market weight would be due to retail product weight.

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[1]Koch is a professor of animal science, University of Nebraska-Lincoln, stationed at MARC; Gregory is the research leader, Production Systems Unit; and Cundiff is the research leader, Genetics and Breeding Unit, MARC.

[2]For a detailed description of the analysis reported here, see Journal of Animal Science 55:1319-1329, 1982.

Table 1.—Age constant means($\bar{x}$), heritabilities (h^2), and genetic and phenotypic correlations[a]

Item	$\bar{x}$	h^2	1	2	3	4	5	6	7	8	9	10	11
1. Feedlot gain, lb/day	2.37	.57		.72	.66	−.15	.37	.15	.61	−.12	.17	.32	.07
2. Side weight, lb	311.5	.43	.89		.84	−.31	.62	.34	.72	−.34	.36	.43	.13
3. Retail weight, lb	212.7	.58	.73	.81		.23	.13	−.19	.77	−.07	−.05	.60	−.07
4. Retail percentage	68.8	.63	−.13	−.11	.46		−.91	−.98	.06	.50	−.74	.27	−.37
5. Fat trim weight, lb	58.6	.47	.40	.45	−.12	−.91		.94	.13	−.64	.77	−.03	.36
6. Fat trim percentage	18.6	.57	.12	.13	−.44	−.98	.94		−.14	−.65	.77	−.20	.38
7. Bone weight, lb	39.0	.57	.79	.71	.72	.14	.03	−.25		.40	−.08	.30	−.05
8. Bone percentage	12.6	.53	.02	−.20	.03	.35	−.51	−.51	.54		−.59	−.16	−.24
9. Fat thickness, in	.48	.41	.05	.08	−.34	−.74	.74	.78	−.30	−.52		−.15	.24
10. Rib eye area, in^2	11.3	.56	.34	.44	.72	.53	−.28	−.48	.35	−.04	−.44		.03
11. Marbling[b]	10.5	.40	.15	.25	−.02	−.37	.42	.34	.15	−.04	.16	−.14	

[a]Genetic correlations are given at the left of the diagonal and phenotypic correlations at the right. Column numbers correspond to row numbers.
[b]Marbling scores: slight = 7, 8, 9; small = 10, 11, 12; modest = 13, 14, 15; moderate = 16, 17, 18, *etc.*

Table 2.—Expected response to one standard deviation of selection for (1) daily gain in feedlot, (2) side weight, (3) retail product percentage, and (4) reduced fat thickness

		Selection criteria (and standard deviations)			
Item	Basis[a]	1 (.258)	2 (26.5)	3 (3.3 pct)	4 (.134)
Side wt, lb	CA	11.7	11.4	−1.5	−.9
Retail wt, lb	CA	7.7	7.4	5.1	3.0
	CW	2.3	2.1	5.8	3.4
Retail percentage	CA	−.3	−.2	2.1	1.2
	CW	.7	.7	1.9	1.2
Fat trim wt, lb	CA	2.9	2.8	−7.0	−4.6
	CW	−2.8	−2.7	−6.2	−4.1
Fat trim percentage	CA	.3	.2	−2.2	−1.4
	CW	−.9	−.9	−2.0	−1.3
Bone wt, lb	CA	1.6	1.2	.3	.5
	CW	.9	.5	.4	.6
Bone percentage	CA	.0	−.1	.2	.2
	CW	.3	.2	.1	.2
Fat thickness, in	CA	.00	.00	−.05	−.05
	CW	−.03	−.03	−.05	−.05
Rib eye area, in^2	CA	.2	.2	.4	.2
	CW	.1	.1	.4	.2
Marbling[b]	CA	.2	.3	−.5	−2.
	CW	−.2	−.1	−.5	−.2

[a]CA is at a constant age and CW is at a constant weight.
[b]Marbling a change of one degree of marbling, e.g., from slight to small is equivalent to 3.0 score units.

Length of Feeding Interval Influences Accuracy of Selection for Growth

Robert M. Koch, Larry V. Cundiff, and Keith E. Gregory[1,2]

Introduction

Rapid growth is an important trait for market beef production. Faster growth rate increases the proportion of feed intake that is used for building body tissues and reduces total input/unit of weight gain. This happens because over one-half of the feed energy and nearly two-thirds of the total cost for growing the beef animal goes to maintain normal life processes.

Selection for increased growth rate has been directed largely at postweaning gain because it is highly heritable. Performance tests to evaluate postweaning gain generally vary in length from 112 to 252 days with initial dates beginning at weaning or 30 to 60 days after weaning. The optimum length is determined by the heritability of gains, by cost, and by availability of records early enough to make selection decisions before the first breeding season. Heritability is the fraction of the observed differences between animals caused by average genetic effects, and selection accuracy increases as heritability increases.

A study was made to determine whether the interval length for postweaning adjustment and gain evaluation influenced the heritabilities and genetic correlations of gains evaluated for different time periods.

Procedure

The data included postweaning gains over a 224-day interval of (1) 2,410 crossbred steers from 313 sires representing 16 breeds and (2) 3,088 Hereford bulls from 180 sires. The crossbred steers were part of the germ plasm evaluation program at MARC. Records on the 3,088 Hereford bulls were collected over a 15-year period as part of a long-term selection experiment at MARC.

Weaning weight and eight postweaning weights obtained at 28-day intervals were used to calculate daily gains for all possible intervals of 28 days to 224 days.

Results

Heritabilities of 28- to 224-day gains. Heritabilities for the gain intervals are reported in Table 1. Heritabilities (h^2) in these data are useful primarily for describing the relative expression of average genetic effects for different lengths of feeding intervals in these two cattle populations. Heritabilities estimated from the germ plasm evaluation (GPE) data were higher than those estimated from the selection experiment. Although the difference in heritability for the two data sets is not pertinent to the primary objective of the study, it may be worth speculating on reasons for the differences other than sampling error.

Average genetic effects in the GPE data are from steers and an average of sire differences within 16 sire breeds as expressed in cross combination with Hereford or Angus dams. Gains of crossbred progeny would be increased by heterosis, and this could produce a scaling effect for increased genetic variation, if variation is proportional to the mean level of performance. An increased tolerance to environmental differences among crossbreds could reduce the relative expression of environmental *vs* genetic effects and, therefore, increase heritability. Sires in GPE came from many herds and were unselected for growth rate. It has been reported that heritability of gain was 35 percent higher when calculated among progeny of sires from different herds than among progeny of sires within herds. The selection experiment data involved bulls from four closed lines of one breed. Intense selection for growth rate among Hereford bulls in the selection experiment would reduce sire variation. Calculations based on the expected impact of selection intensity in the experiment indicate that the heritability estimate of .24 (224 days) in Table 1 should be adjusted upward to .30.

As length of the feeding interval increased from 28 to 224 days, the average heritability for these intervals increased, but at a declining rate. Heritability averages increased from .12 to .55 for steers in the GPE data and increased from .09 to .24 for bulls in the selection experiment data. The trend for heritability to increase more in steers than in bulls as length of feeding interval increased may be due to sexual behavior of puberal bulls interacting with appetite to reduce genetic variation in gain relative to that of steers which are not sexually aggressive. Thus, breeders should choose the longest interval that is practical for management and breeding decisions.

Table 1.—Heritabilities of gains from 28 to 224 days

	Length of postweaning interval, days							
Data source	28	56	84	112	140	168	196	224
GPE	.12	.27	.35	.40	.46	.49	.52	.55
Selection experiment	.09	.13	.16	.19	.21	.21	.21	.24

[1]Koch is a professor of animal science, University of Nebraska-Lincoln, stationed at MARC; Cundiff is the research leader, Genetics and Breeding Unit; and Gregory is the research leader, Production Systems Unit, MARC.

[2]A detailed discussion of procedures was described in the Journal of Animal Science 55:1310-1318, 1982.

Characterization of Breeds Representing Diverse Biological Types: Reproduction and Maternal Performance of F_1 Cows

Larry V. Cundiff, Keith E. Gregory, and Robert M. Koch[1]

Introduction

It is estimated that today about 70 percent of the calves marketed from beef cattle herds in the U.S. are crossbred and that between 50 and 60 percent of the cows are crossbred. This represents a major shift to crossbreeding from the straightbreeding programs which prevailed in the 1950's and early 1960's. This trend has been influenced by research demonstrating the favorable effects of heterosis and other advantages of crossbreeding. Also, increased use of feed grains in growing-finishing diets caused fatter carcasses contributing to increased consumer demand for leaner beef, which stimulated interest in breeds with greater potential for lean tissue growth and less fat. As a result, a large number of breeds, introduced from Europe via quarantine facilities in Canada, became available to North American beef producers. Interest in the newly introduced breeds and in other breeds already available coincided with the establishment and development of the Roman L. Hruska U.S. Meat Animal Research Center (MARC) in the late 1960's. The Germ Plasm Evaluation (GPE) Program was initiated in 1969 at MARC to characterize a broad range of biological types of cattle as represented by breeds that differed widely in genetic potential for milk production, growth rate, carcass composition, and mature size. The purpose of this paper will be to review results from the GPE Program for reproduction and maternal characteristics of first cross (F_1) cows.

Procedure

The Germ Plasm Evaluation (GPE) Program has included three cycles of sire breeds that were mated by artificial insemination (AI) to Hereford and Angus cows. The first cycle involved breeding Hereford (H), Angus (A), Jersey (J), Limousin (L), South Devon (SD), Simmental (S), and Charolais (C) sires by AI to Hereford and Angus dams (ranging from 2 to 7 yr of age at calving) to produce three calf crops in March and April of 1970, 1971, and 1972. In Cycle II, the Hereford and Angus dams used in Cycle I were bred by AI to Hereford, Angus, Red Poll (R), Brown Swiss (B, predominantly European), Gelbvieh (G), Maine Anjou (MA), and Chianina (Ci) sires to produce two calf crops in 1973 and 1974. Cycle III involved the same or comparable Hereford and Angus dams (ranging from 4 to 11 yr old at calving) mated by AI to Hereford, Angus, Tarentaise (T), Pinzgauer (P), Sahiwal (Sw), and Brahman (Br) sires to produce two calf crops in 1975 and 1976.

The same Hereford and Angus sires were used in all three cycles of the program to provide a control population of Hereford-Angus reciprocal crosses (HA) for comparing breeds used in different cycles of the program. The females produced in the program were retained to evaluate reproduction and maternal performance when raising three-way cross calves by sires of a different breed. Calves were born in the spring (March and April) when the cows ranged from 2 to 8 years of age. The data will be presented for 15 F_1 crosses classified into six biological types based on growth rate and mature size, lean to fat ratio, age at puberty, and milk production (Table 1).

Results

Results on production of F_1 cows are summarized in Table 2. The data on Cycle I cows (HA, J, L, SD, S, and C) were for ages 2 through 8 years; Cycle II cows (HA, R, B, G, MA, and Ci), ages 2 through 7 years; and Cycle III cows (HA, P, T, Br, and Sw), ages 2 through 7 years, except for milk production estimates taken when the cows were 3 and 4 years of age. Data for the F_1 cows in this report were pooled over all three cycles of the program by adding the average differences between Hereford-Angus reciprocal crosses and other breed groups within each cycle to the average of Hereford-Angus crosses over all three cycles.

Breed group means for percentage calf crop born ranged from 88 to 95 percent and, for percentage calf crop weaned, from 83 to 89 percent. Only the most extreme differences are statistically significant (about 4 pct for comparisons in the same cycle and 6 pct for comparisons in different cycles). Differences between breed groups in calf crop percentage born reflect variation among breeds in reproduction rate and prenatal survival, while calf crop percentage weaned reflects variation in these factors plus postnatal survival. Sahiwal, Brahman, Gelbvieh, Maine Anjou, and Pinzgauer crosses tended to have the highest calf crop percentages, especially at birth. The advantages for Brahman and Sahiwal crosses may be associated with greater effects of heterosis on reproduction which have been reported for *Bos indicus* x *Bos taurus* breed crosses compared to *Bos taurus* x *Bos taurus* breed crosses. The relatively high reproductive rates for a number of breeds representing biological types with high milk production potential and medium to large size indicate that the nutritional environment at MARC has been adequate to meet the requirements for growth, lactation, and maintenance, of even the highest producing breed groups. Results from other experiments have indicated that, if the added nutrient requirements of cows with large size and higher milk production potential are not met, the interval from calving to estrus increases and conception rate declines.

Sahiwal and Brahman cross females experienced less calving difficulty than other breed groups. Results summarized in Table 2 are for ages from 2 through 7 years, but the advantage of Sahiwal and Brahman cross females was of greatest magnitude for heifers calving as 2-year-olds. The low calving difficulty for Sahiwal and Brahman F_1 dams was associated with the low birth weights of their progeny. Indications are that the low birth weight and low calving difficulty for Sahiwal and Brahman F_1 females were associated with a strong maternal effect rather than a direct genetic effect transmitted from parent to offspring. In the earlier phase of the experiment, when F_1 calves out of Hereford and Angus dams were compared, Brahman-sired calves were above average in birth weight (3rd out of 15) and calving difficulty (6th out of 15), and Sahiwal crosses were about average (9th and 11th out of 15, respectively).

Among the *Bos taurus* x *Bos taurus* breed crosses, the association between breed-of-dam means for calving difficulty and birth weight of progeny is low. For example, Chianina and Brown Swiss dams experienced relatively low calving difficulty (8 pct, ranking 4th and 5th) considering the relatively high birth weight of their progeny (95 and 91 lb, ranking 2nd and 3rd, respectively). In the earlier phase of the experiment, the association between birth weight and calving difficulty was much stronger when only direct genetic effects transmitted from sire to offspring were involved—breeds that sired calves with the heaviest birth weights also required the greatest assistance at calving.

Breeds that have had a history of selection for milk production (e.g., J, B, G, S, P, T) excelled in milk production, while

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those with a history of selection only for meat production or draft had lower levels of milk production (HA-X, L, C, Ci). The Red Poll and South Devon produced intermediate levels of milk. Brahman and Sahiwal crosses produced relatively high levels of milk, comparable to that of *Bos taurus* breeds with a long history of selection for milk production.

Breed group means for cow weight shown in Table 2 were taken at weaning time after a lactation period of about 7 months. Thus, differences among breed groups in cow weight reflect differences in fatness inversely associated with variation in milk production as well as differences in mature size that are associated positively with skeletal size and lean tissue growth rate.

The differences among F_1 cow breed groups for 200-day weight per calf weaned reflect variation in milk production and genetic potential for growth, while those for 200-day weight per cow exposed also reflect variation in calf crop percentage weaned. There were large differences among F_1 cow breed groups for 200-day weaning weight per cow exposed. Output was greatest for *Bos indicus* x *Bos taurus* crosses (Br and Sw), and large-sized, dual purpose breeds (B, G, S, MA) excelling in milk production and genetic potential for growth. Relative to mature size of the cows, outputs were especially high for the Sahiwal crosses. Calf weight output of dual purpose breeds with intermediate size (P, T, and SD) was intermediate to that of Hereford-Angus crosses and larger, higher milking, dual purpose types (B, G, S, and MA). Output of Limousin and Charolais cross cows was similar to that of Hereford x Angus crosses. The extra growth rate of progeny out of Charolais cows was offset by a relatively higher calf crop percentage for Hereford-Angus cows. Output of Chianina cross cows was high relative to Hereford-Angus, Limousin, and Charolais, due to relatively high calf crop percentages and weaning weight. Output of Jersey crosses exceeded that of Hereford-Angus crosses by about 4 percent, reflecting higher milk production. The higher milk production of Red Poll crosses was offset by a lower calf crop weaned, so that differences between Red Poll and Hereford x Angus F_1 cross cows were small for 200-day weaning weight per cow exposed.

Table 1.—Breed crosses grouped in biological type on basis of four major criteria and number of females initially assigned to breeding as yearling heifers

	Biological type criteria[a]				
Breed group	Growth rate & mature size	Lean to fat ratio	Age at puberty	Milk prod.	No. females
Jersey-X (J)	X	X	X	XXXXX	117
Hereford-Angus-X (HA)	XX	XX	XXX	XX	322
Red Poll-X (R)	XX	XX	XX	XXX	95
South Devon-X (SD)	XXX	XXX	XX	XXX	120
Tarentaise-X (T)	XXX	XXX	XX	XXX	85
Pinzgauer-X (P)	XXX	XXX	XX	XXX	114
Sahiwal-X (Sw)	XX	XXX	XXXXX	XXX	87
Brahman-X (Br)	XXXX	XXX	XXXXX	XXX	103
Brown Swiss-X (B)	XXXX	XXXX	XX	XXXX	126
Gelbvieh-X (G)	XXXX	XXXX	XX	XXXX	81
Simmental-X (S)	XXXXX	XXXX	XXX	XXXX	157
Maine Anjou-X (MA)	XXXXX	XXXX	XXX	XXX	89
Limousin-X (L)	XXX	XXXXX	XXXX	X	161
Charolais-X (C)	XXXXX	XXXXX	XXXX	X	132
Chianina-X (Ci)	XXXXX	XXXXX	XXXX	X	92

[a]Increasing number of "X's" indicate relative difference between breeds.

Table 2.—Breed group means for reproduction and maternal performance of F_1 cows out of Hereford and Angus dams by 16 sire breeds

		Calf crop						200-day weight			
Breed group	No. births	Born, pct	Weaned, pct	Calving difficulty,[a] pct	Birth weight,[b] lb	Milk prod.,[c] lb	Cow weight,[d] lb	Per calf weaned,[b] lb	Ratio,[e] pct	Per cow exposed, lb	Ratio,[e] pct
Jersey-X (J)	628	90	84	7	79	9.2	1,068	493	104	417	104
Hereford-Angus-X (HA)	1,685	91	84	13	86	6.1	1,224	475	100	401	100
Red Poll-X (R)	461	90	79	14	89	7.5	1,171	502	106	396	99
South Devon-X (SD)	603	88	85	15	91	6.5	1,265	492	104	419	105
Tarentaise-X (T)	369	91	85	10	88	7.9	1,205	524	110	445	112
Pinzgauer-X (P)	508	93	85	13	91	8.0	1,219	509	107	432	108
Sahiwal-X (Sw)	431	95	89	2	76	8.5	1,119	502	106	446	112
Brahman-X (Br)	519	94	86	1	83	9.1	1,284	539	114	463	116
Brown Swiss-X (B)	681	92	85	8	91	8.3	1,242	534	112	454	114
Gelbvieh-X (G)	429	95	87	11	90	8.3	1,285	533	112	464	116
Simmental-X (S)	872	89	83	17	91	8.3	1,281	521	110	433	108
Maine Anjou-X (MA)	468	94	86	11	96	6.4	1,365	522	110	449	112
Limousin-X (L)	851	89	82	12	88	5.5	1,234	484	102	397	100
Charolais-X (C)	693	88	80	15	93	5.5	1,356	503	106	403	101
Chianina-X (Ci)	475	93	86	8	95	6.1	1,369	523	110	450	113

[a]Includes calves requiring calf puller or Caesarean section.
[b]Adjusted to a steer basis.
[c]Average of three 12-h milk production measures on a sample of 18 cows per breed group at 3 and 4 years of age.
[d]Cow weight taken in fall at weaning time when cows were 7-year-olds.
[e]Ratio computed relative to average for Hereford-Angus reciprocal cross dams.

Genetic Correlations of Reproductive and Maternal Traits with Growth and Carcass Traits in Beef Cattle

Michael D. MacNeil, Larry V. Cundiff, C. A. Dinkel, and Robert M. Koch[1]

Introduction

Some genes may affect more than one trait. Therefore, the traits can be genetically correlated. Knowledge of genetic correlations among traits is useful for efficient selection of replacement bulls and heifers if the breeder considers more than one trait. In designed selection programs, emphasis to be placed on the various traits can depend, in part, on the genetic correlations among them. In addition, genetic correlations can be used to predict what is expected to happen to traits other than those used in selection as a result of that selection. This effect on traits other than those used in selection is referred to as correlated response.

The objective of this study was to estimate from experimental data the genetic correlations between reproductive and maternal traits of beef females and growth and carcass traits of paternal half-sib steers. A more detailed account of the methodology and results can be found in the Journal of Animal Science, volume 58, pages 1171 to 1180.

Procedure

This study includes data on calves born at MARC during 1970, 1971, and 1972. Straightbred Hereford and Angus cows were mated to either Hereford, Angus, Jersey, South Devon, Limousin, Charolais, or Simmental sires to calve from late February to early May. Bull calves were castrated at birth, and all calves had access to creep feed from mid-July until weaning in late October.

After weaning, heifers were fed *ad libitum* a diet of approximately 50 percent corn silage and 50 percent grass haylage with supplemental protein and minerals. Heifers were observed for estrous activity twice daily from approximately 250 to 510 days of age, except in 1971, when estrous detection ceased at about 480 days of age. A breeding season of approximately 65 days started when the average age of all heifers was 430 days. During the first two-thirds of the breeding season, all heifers were artificially inseminated with semen from either Hereford, Angus, Devon, Holstein, or Brahman bulls. In the latter one-third of the breeding season, natural service Hereford and Angus sires were used.

Postweaning management of steer calves differed from that of their half-sib heifers. After a 25- to 30-day adaptation period, steers were implanted with 36 mg diethylstilbestrol (DES) and assigned to feedlot pens with fence-line bunks. Steers were also fed *ad libitum,* but the dietary energy density increased periodically as they matured. Steers were slaughtered in one of three groups at about one-month intervals. The initial slaughter group was killed after 190 days on feed in 1971, 169 days in 1972, and 194 days in 1973. The right side of each carcass was transported to Kansas State University. Sides were cut into wholesale cuts and cuts fabricated into boneless (except for rib and short loin), closely trimmed (.3 in) retail product (steaks, roasts, and lean trim), fat trim, and bone.

Results

Estimated heritabilities for the traits studied are presented in Table 1. Heritability estimates for age and weight at first observed estrus, or puberty (61 pct and 70 pct, respectively), are somewhat higher than previously reported estimates. The 3 percent heritability for conceptions/service in this study is in agreement with previous estimates for fertility, whether measured as calving rate, conception/service, or services/conception. Gestation length and calf birth weight have been implicated in the incidence of dystocia and calf mortality. In this study, gestation length, calf birth weight, calving difficulty, and preweaning daily gain were treated as traits of the cow. Heritability estimates were 30 percent for gestation length, 37 percent for calf birth weight, and 22 percent for calving difficulty. The heritability estimate for preweaning gain of the calf, as a trait of the dam, was 9 percent. Previous studies suggest the heritability of preweaning gain, as a trait of the dam, lies in the range of 17 to 34 percent. The heritability of preweaning gain, as a trait of the calf, was also found to be low (7 pct) in these data.

The amount of feed eaten by a cow is related to her weight. Therefore, cow size may be important in the evaluation of alternative selection objectives. Mature weight has been one commonly used measure of size. The estimated heritability of the average of four weights taken at 7 years of age was 54 percent in this study.

Heritability estimates for daily gain (36 pct), carcass weight (44 pct), retail product weight (45 pct), and trimmed fat weight (50 pct) found in this study are comparable with other estimates in the literature. Selection to increase (or decrease) any of these traits measured on steers should be effective.

Also presented in Table 1 are estimated genetic correlations of traits expressed in males and females. Postweaning daily gain, carcass weight, and retail product weight at a constant age seem to have similar genetic associations with the complex of female reproductive and productivity traits studied.

Since retail product weight and carcass weight had essentially equal heritabilities, predicted correlated responses to selection for either trait are also similar. Predicted correlated responses to selection for either retail product weight or carcass weight are greater in magnitude than those for daily gain selection, due primarily to the higher heritabilities of the former traits. Selection for increased carcass weight or retail product weight of steers at a constant slaughter age should result in heifers that are older and heavier at puberty and have slightly improved fertility. The gestation length of these heifers and calf birth weight would increase slightly, although, maternally, calving would occur with less difficulty. The inconsistency of a larger calf and less calving difficulty is perhaps explained by the increased size of the heifer.

Selection for decreased fat recently has received considerable attention. While this course of action may result in more desirable carcasses, the genetic correlations found in this study may indicate possible problems. Females from sires selected for reduced fat trim of steer progeny would be expected to reach puberty later and at a heavier weight, have reduced fertility, and be larger at 7 years of age. These data also suggest a longer first gestation with the resultant calf born heavier and with greater difficulty.

These results document the existence of unfavorable genetic correlations between component traits of female productivity and progeny carcass value. Therefore, specialized sire and dam lines appear to merit consideration in beef production. Alternatively, selection indexes that incorporate both carcass value traits and maternal productivity traits provide logical selection objectives in general purpose populations. Genetic progress in a general purpose population would be slower than progress that could be made from crossing sire and dam lines selected for specialized roles.

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Table 1.—Estimated genetic correlations of reproductive and material traits with growth and carcass traits. In parentheses are the respective heritability estimates (h^2) and the number of heifers or steers (n)[a]

Reproductive and maternal traits of females	Growth and carcass traits of steers			
	Daily gain (h^2 = .36; n = 1,095)	Carcass wt (h^2 = .44, n = 1,071)	Fat trim wt (h^2 = .50; n = 1,071)	Retail product wt (h^2 = .45; n = 1,064)
Age at puberty (h^2 = .61; n = 813)	.16	.17	−.29	.30
Weight at puberty (h^2 = .70; n = 841)	.07	.07	−.31	.08
Conceptions/service (h^2 = .03; n = 771)	+[b]	.61	.21	.28
Gestation length (h^2 = .30; n = 580)	−.10	.03	−.07	.13
Calving difficulty (h^2 = .22; n = 590)	−.60	−.31	−.36	−.02
Birth weight (h^2 = .37; n = 581)	.34	.37	−.07	.30
Preweaning daily gain (h^2 = .09; n = 624)	—[b]	—[b]	—[b]	−.26
Mature weight (h^2 = .54; n = 639)	.07	.21	−.09	.25

[a]Genetic correlations have an expected range from −1.0 to +1.0. Estimates in the ranges .7 to .10 and −.7 to −1.0 indicate strong positive and negative genetic relationships between traits, respectively. Estimates from −.2 to .2 indicate weak genetic relationships between traits.

[b]The estimated genetic correlation was either greater than +1.0 or less than −1.0. Only the sign of the estimate has been reported.

Effects of Heterosis on Longevity in Beef Cattle

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Introduction

Longevity can be important to the economic efficiency of beef production. The longer cows remain productive in a herd, the fewer the number of replacement heifers needed and the greater the calf output per cow maintained. In this way, more heifers can be sold for feeding and slaughter, and the cost of growing out replacement females to a productive age is reduced. Less culling of infertile cows also increases output per cow exposed. This study was conducted to determine effects of heterosis on longevity and associated factors in crosses of the Hereford, Angus, and Shorthorn breeds.

Procedure

Data were studied on 328 cows produced from 1960 through 1963 at the Fort Robinson Beef Cattle Research Station, Crawford, Nebraska, in a crossbreeding experiment comparing all possible reciprocal crosses and straightbreds of the Hereford, Angus, and Shorthorn breeds. The 155 females born in 1960 and 1961 were managed to calve first as 3-year-olds, and the 173 females born in 1962 and 1963 were managed to calve first as 2-year-olds. The cows were transferred to MARC in 1972, and the experiment was continued until 1975. At this time, the cows ranged from 12 to 15 years of age. Table 1 shows the number of females for each breed group assigned to breeding pastures to initiate the experiment in 1962-1964 and the mating plans followed from 1963 until 1975.

The cows were wintered on native range with the protein requirement provided by feeding either alfalfa hay or a 40 percent protein supplement. Hay was fed *ad libitum* when needed during storm periods prior to calving and during the calving seasons. All cows calved in the spring. The length of the breeding season was about 75 days, commencing in late May or early June each year. Cows were diagnosed for pregnancy in the fall each year.

Cows were culled because of reproductive failure or severe unsoundness. Heifers diagnosed as not pregnant at the end of their first breeding season were culled. After the first breeding season and until they were 10 years of age, only cows failing to conceive in two successive years or sick or injured cows were culled. Cows 10 years old and older were culled the first time they were open. Other than reproductive failure, cows were removed for the following reasons: death, crippled, unsound udder, cancer eye, lump jaw, prolapse, emaciation, and unknown.

Longevity was measured as the age of the cow at disposal, which is the difference between date of disposal (or date at the end of the experiment) and birth date. In addition to this "actual" culling policy (A), an "imposed" culling policy (I) was studied in which all open cows would be removed at their first year of failure to conceive. This procedure differed from the actual policy only for cows from their second breeding season through 9 years of age, when in actual practice only those cows failing to conceive in two successive years were culled for being open. Under the imposed culling policy, date of disposal was considered to be October 27 of the year when the cow failed to conceive.

Information on teeth of cows was recorded at weaning time in the last three years of the experiment (1973 through 1975). Size of each of the eight incisors was scored 0 for no tooth, 1 for a tooth less than .08 in, 2 for a tooth .08 in to .3 in, and 3 for a tooth longer than .3 in. Data are presented on the total score for all eight incisors. In addition, condition of incisors was classified as: 1 = good condition, 2 = broken, 3 = loose, 4 = broken and loose, and 5 = missing.

Results

Longevity, or the age at disposal from the herd, is shown in Table 2 for each breed group under the actual and imposed culling policies. In actual practice, crossbred cows survived 1.4 years longer than straightbred cows, a heterosis effect of 16 percent. If females were culled the first time they were open, crossbred cows would have survived 1.0 year longer than straightbred cows, a heterosis effect of 15 percent. The range of longevity among breed groups was 3.75 years, with Hereford-Angus reciprocal crosses at the upper limit and Shorthorn straightbred cows at the lower limit. Among straightbreds, Angus survived longer than Shorthorns, but neither differed significantly from Herefords. Angus crosses (A-X = average of AH, HA, AS, and SA) also exceeded Hereford and Shorthorn crosses in longevity under both the actual (A-X = 10.2, H-X = 9.8, S-X = 9.2 yr) and imposed (A-X = 8.3, H-X = 7.8, S-X = 7.0 yr) culling policies.

Survival was estimated as the proportion of cows exposed in each successive breeding season relative to the initial number of cows (Fig. 1). Survival of crossbred cows was greater than that for straightbreds throughout life under both the actual and imposed culling policies. Heterosis for survival of cows tended to increase with age and became statistically significant at 11 and 12 years of age.

Reasons for disposal and average age at disposal under the actual culling policy are presented in Table 3 for crossbred and straightbred cows. The main reason for disposal was infertility, which accounted for more than 50 percent in both breed groups, but the mean age at disposal for this reason was older for crossbred (7.9 yr) than for straightbred (6.5 yr) cows. The reason of second importance was mortality (death) in which straightbreds (19.9 pct) had greater losses than crossbreds (10.5 pct). Problems of poor body condition (emaciation) were more frequent in straightbred (7.1 pct) than crossbred (4.1 pct) cows, and these removals occurred at older ages (12 and 13 yr, respectively). Losses of crippled cows were similar for straightbred and crossbred cows but occurred at older ages (10.5 and 11.4 yr, respectively) in crossbreds. Unsound udders developed more frequently in crossbred cows than in straightbreds but at a relatively old average age of 12.8 years. Only four cows were culled for cancer eye, and they were all straightbred Herefords (2.6 pct at an average age of 11.1 yr). One Hereford cow was culled for lump jaw at 8.6 years of age, and two Hereford and one Angus exhibited prolapse at an average age of 3.9 years. At the end of the experiment, a higher proportion of crossbred (19.2 pct) cows were pregnant and in good condition than straightbreds (6.4 pct). In general, mortality and survival at the end of the experiment were the main reasons for differential disposal rates in favor of crossbred cows over straightbred cows.

Length of teeth was studied using the sum of the incisor size scores for all eight incisors. Incisor length decreased with age from 10 to 15 years for all breed groups, and the wear rate appeared to be higher during the younger ages (Fig. 2). The differences in sum of incisor length scores between 10- and 11-year-old cows was approximately 4, or more than a com-

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plete tooth, and the difference between 14- and 15-year-old cows was about 1, or less than 2 mm. Apparently, younger cows have more and longer teeth that may be affected more by wear than older cows. Crossbred cows had significantly longer incisors than straightbred cows.

Condition of teeth: Frequency of normal, broken, loose, broken and loose, and missing incisors is presented in Figure 3 for each breed group. Frequency of normal teeth ranged from 71 percent in the Hereford to 99 percent in Angus-Hereford crosses. On the average, crossbred cows had 88.9 percent normal teeth compared to 83.3 percent normal teeth for straightbred cows. Missing teeth accounted for most of the variation among breed groups in condition of incisors. Hereford cows had the most and Angus-Hereford cows had the fewest missing teeth. Variation among breed groups in broken teeth, loose teeth, or broken and loose teeth were small and generally not significant.

Table 1.—Number of females per breed group and mating plans to produce calf crops from 1963 through 1975

		Years						
		1963-1968[a]			1969-1972[b]			1973-1975
		Sires						
Dams	Number	H[c]	A	S	H	A	S	R
H	53		X	X	X			X
A	51	X		X		X		X
S	52	X	X				X	X
HA	29			X	X	X	X	X
AH	24			X	X	X	X	X
HS	30		X		X	X	X	X
SH	32		X		X	X	X	X
AS	25	X			X	X	X	X
SA	32	X			X	X	X	X

[a]This mating system was used to estimate maternal heterosis in Phase II.
[b]These matings produced the first generation of Phase III.
[c]H = Hereford, A = Angus, S = Shorthorn, R = Red Poll, HA = Hereford sire and Angus dam . . ., SA = Shorthorn sire and Angus dam.

Table 2.—Breed group means and effects of heterosis for longevity (yr) under two culling policies

	Culling policy	
Item	Actual	Imposed
Breed group		
Hereford	8.5	6.9
Angus	9.4	7.6
Shorthorn	7.3	5.6
Hereford-Angus	11.0	8.8
Angus-Hereford	10.6	9.4
Hereford-Shorthorn	8.0	5.3
Shorthorn-Hereford	9.6	7.6
Angus-Shorthorn	9.3	6.8
Shorthorn-Angus	9.9	8.3
Crossbred average	9.7	7.7
Purebred average	8.4	6.7
Differences (heterosis)	1.3	1.0

[a]*Actual culling policy.* Heifers and cows 10 years old or older diagnosed as not pregnant were culled the first time they were open. After the first breeding season through 9 years of age, cows failing to conceive in two successive breeding seasons were culled. Cows were also culled for severe unsoundness.

Imposed culling policy. Females were culled the first time they were open, regardless of age, and for severe unsoundness.

Table 3.—Reasons for disposal and average age (yr) at removal from cow herd

	Straightbreds			Crossbreds		
Reason	No.	pct	Age	No.	pct	Age
Open	85	54.5	6.5	91	52.9	7.9
Death	31	19.9	10.1	18	10.5	9.0
Emaciation	11	7.1	12.0	7	4.1	13.1
Crippled	5	3.2	10.5	7	4.1	11.4
Unsound udder	0	0.0	- - -	9	5.2	12.8
Cancer eye	4	2.6	11.1	0	0.0	- - -
Prolapse	3	1.9	3.9	0	0.0	- - -
Lump jaw	1	.6	8.6	0	0.0	- - -
Unknown	6	3.8	5.4	7	4.1	4.6
End of experiment	10	6.4	13.1	33	19.2	13.2
Total	156	100	9.0	172	100.0	10.3

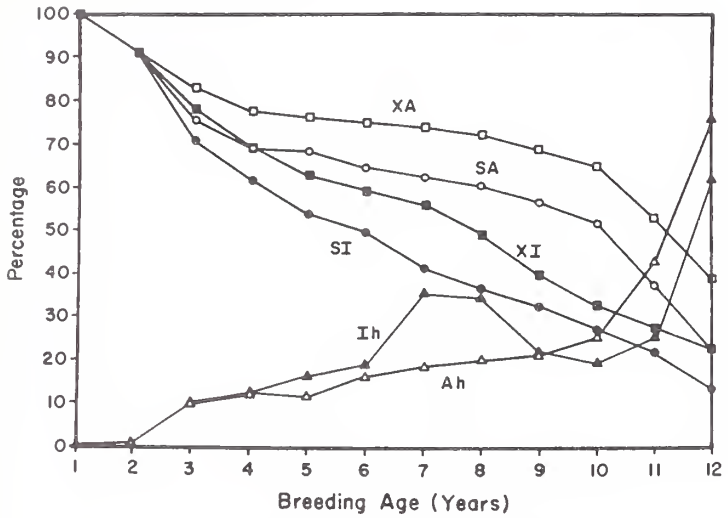

Figure 1—Cumulative survival of straighbred (S) and crossbred (X) cows and percent of heterosis (h) under both actual (A) and imposed (i) culling policies.

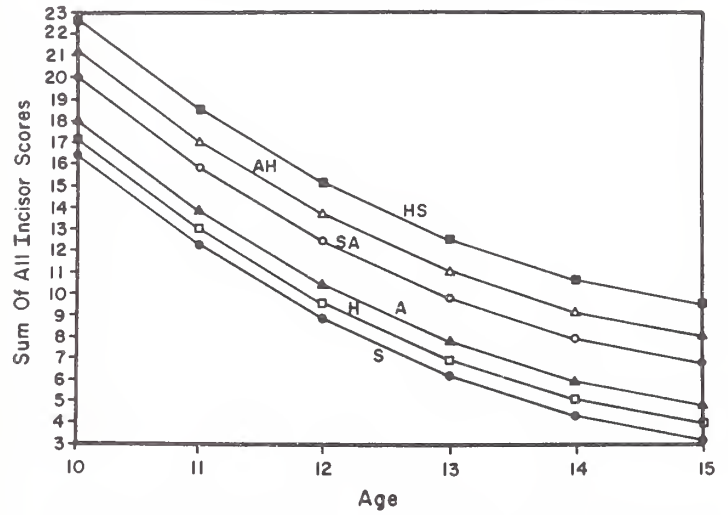

Figure 2—Effect of age on teeth length of straightbred Hereford (H), Angus (A), Shorthorn(s) and reciprocal cross cows.

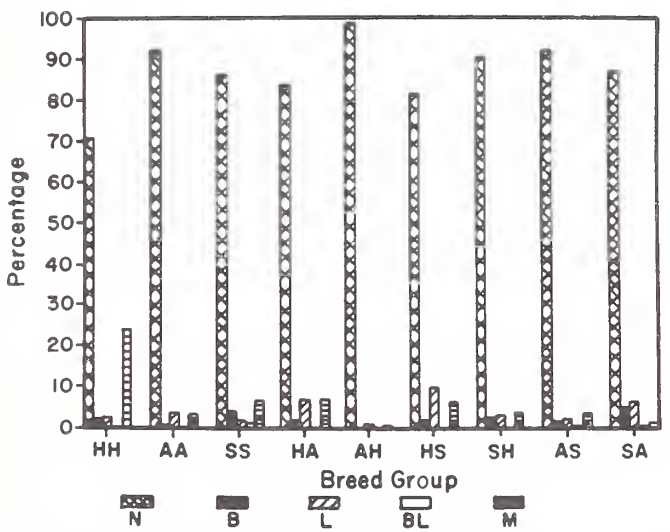

Figure 3—Relative frequency of normal (N), broken (B), loose (L), broken and loose (BL), and missing (M) teeth in aged (10 to 15 yr) cows.

Effects of Heterosis on Lifetime Production in Beef Cows

Larry V. Cundiff, Rafael Nunez-Dominquez, Gordon E. Dickerson, Keith E. Gregory, and Robert M. Koch[1]

Introduction

Results from a crossbreeding experiment conducted at the Fort Robinson Beef Cattle Research Station with Herefords, Angus, Shorthorns, and their reciprocal crosses demonstrated that weaning weight per cow exposed to breeding was increased 23 percent/year by favorable effects of heterosis on survival and growth of crossbred calves and by improved reproduction and maternal ability of crossbred cows. More recent results have shown that heterosis also increases longevity of beef cows. The present study was conducted to evaluate total effects of heterosis on longevity, calf crop percentage weaned, and weaning weights of progeny when combined into one trait (lifetime production of calf weight weaned per cow entering the breeding herd).

Procedure

Data were studied on 172 crossbred and 156 straightbred females which were produced by mating Hereford, Angus, and Shorthorn sires to Hereford, Angus, and Shorthorn dams. Management and culling practices are described in the article "Effects of Heterosis on Longevity of Beef Cattle" in this report.

Results

All females initially assigned to the experiment in 1963 could potentially reach 12 years of age before the experiment was terminated in 1975. Thus, cumulative production was studied through 12 years of age for crossbred and straightbred cows under the actual and imposed culling policies (Table 2).

Under the actual culling policy, crossbred cows were exposed to breeding for 1.2 more breeding seasons (16 pct heterosis) than straightbred cows, reflecting their greater longevity. They also experienced 1.2 more pregnancies (20 pct heterosis), and produced 1.0 more calves at birth (19 pct heterosis), and at weaning (20 pct heterosis). Cumulative production of 200-day weaning weight per crossbred female initially assigned to the experiment was 642 lb greater than that for straightbred cows by 12 years (30 pct heterosis). The 30 percent increase in cumulative production of 200-day weaning weight was primarily due to increased longevity, or survival, of crossbred cows to 12 years (16 pct) as compared to straightbred cows. (This is relative to the number of each breed type initially assigned to breeding pastures as heifers to begin the experiment.) Other components of heterosis in lifetime output of crossbred cows were higher calf crop percentages weaned (7.8 pct heterosis) and heavier weights per calf raised (7.2 pct heterosis).

Under the imposed culling policy, lifetime production for both crossbred and straightbred cows was reduced by culling females the first time they were open, regardless of age. However, the relative advantages of crossbred cows over straightbred cows reflected by effects of heterosis were about the same as those observed under the actual culling policy for number of breeding seasons (16 pct), pregnancies (19 pct), calves born (18 pct), calves weaned (20 pct), and total 200-day weaning weight produced (30 pct).

Cumulative weight of calves weaned to cows 2 through 12 years of age is shown in Figure 1. Each female initially assigned to the experiment is grouped as either crossbred (X) or straightbred (S) under the actual (A) or imposed (I) culling policy. Effects of heterosis on this measure of lifetime production were generally significant at all ages under both culling policies. Under the actual culling policy, heterosis for cumulative 200-day weighing weight increased from 68 lb, or 19 percent, at 3 years of age to 642 lb, or 30 percent, by 12 years of age. The 30 percent increase in lifetime production by crossbred cows was equivalent to 1.55 calves, using an average weight of 414 lb for calves from straightbred cows.

Economic importance of heterosis under the actual and imposed culling policy is estimated in Table 2 considering income from sale of calves at weaning, income from salvage value of cows, and differences in cost of growing replacement heifers. These estimates reflect differences in annual income above replacement costs in herds of 100 cows, assuming all cows surviving to wean a calf at 12 years of age are culled. Annual income above replacement costs was 23 percent ($3,056) greater for crossbred cows than straightbred cows under the actual culling policy and 20 percent ($2,700) greater for crossbred cows than for straightbred cows under the imposed culling policy. Feed and other costs that may be greater for crossbred cows than straightbred cows because of larger size (2.5 percent), greater milk production, and more and larger calves weaned, were not considered in this economic evaluation. Their inclusion would likely reduce, somewhat, the degree of heterosis for economic efficiency of lifetime cow productivity.

Table 1.—Cumulative production to 12 years of age

Trait	Crossbred cows	Straightbred cows	Heterosis	
			units	pct
	Actual culling policy			
Breeding season, no.	8.2	7.1	1.2	16
Pregnancies, no.	7.2	6.0	1.2	20
Calves born, no.	6.6	5.6	1.0	19
Calves alive at 72 h, no.	6.4	5.4	1.0	19
Calves weaned, no.	6.2	5.2	1.0	20
200-day wt weaned, lb	2,798	2,156	642	30
	Imposed culling policy			
Breeding seasons, no.	6.4	5.5	.9	16
Pregnancies, no.	5.7	4.8	.9	19
Calves born, no.	5.3	4.5	.8	18
Calves alive at 72 h, no.	5.1	4.3	.8	18
Calves weaned, no.	5.0	4.1	.8	20
200-day wt weaned, lb	2,256	1,740	516	30

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Table 2.—Estimated annual output for crossbreds and straightbreds in herds of 100 cows

Item	Actual culling		Imposed culling	
	Cross-bred	Straight-bred	Cross-bred	Straight-bred
No. replacement heifers[a]	12.0	13.6	15.0	17.0
No. cow deaths	0.96	2.06	0.84	1.68
Net weaning weight output[b], lb	31,018	26,238	30,343	26,129
Income from calves[c], $	16,439	13,905	16,081	13,848
Salvage value of cows[d], $	4,087	4,099	5,242	5,442
Gross income, $	20,526	18,004	21,323	19,290
Cost of growing replacement heifers[e], $	4,002	4,536	5,002	5,669
Adjusted income[f], $	16,524	13,468	16,321	13,621

[a]The age distribution of cows was assumed to be at equilibrium with all cows removed at 12 years of age.

[b]Gross output minus weight of proportion of replacement heifers required.

[c]Net output of weight at weaning times value (53 cents per lb, averaged 1972 to 1982, USDA Agricultural Statistics, 1983).

[d]Assuming mean cow weight found in study of 1,099 lb for crossbred and 1,054 lb for straightbred cows times value (33.69 cents per lb, averaged 1972 to 1982, USDA Agricultural Statistics, 1983).

[e]From budgets estimated by Nebraska Cooperative Extension Service 1984; a cost from weaning to 14 months of $248.10 per heifer for 2-year-old first calving management and a cost from weaning to 26 months of $433.90 per heifer for 3-year-old first calving management was averaged ($33.50 per heifer) for this analysis.

[f]Value of output free of differences in replacement costs.

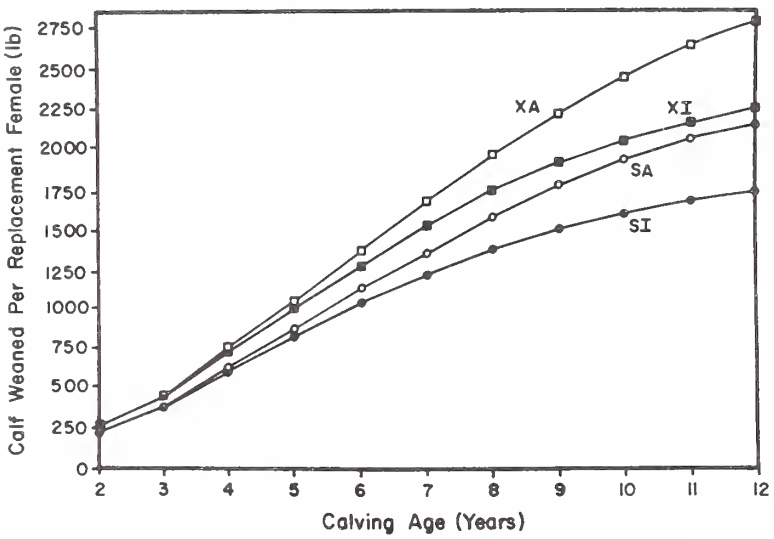

Figure 1—Cumulative calf weight weaned per crossbred (X) and straightbred (S) female initially assigned to breeding under the actual (A) and imposed (I) culling policy.

Heterosis Retention in Advanced Generation Angus-Hereford Crosses

Robert M. Koch, Gordon E. Dickerson, Larry V. Cundiff, and Keith E. Gregory[1,2]

Introduction

Crossbreeding in beef cattle is a widely accepted production practice that influences about 70 percent of the cattle marketed in the United States. Systematic crossbreeding provides for use of heterosis and of differences among breeds to optimize average genetic merit of performance traits for adaptability to the various climatic and nutritive environments encountered in beef production. Because low reproduction rate restricts the use of specialized crossbreeding systems, it is generally assumed that rotational crossbreeding is an efficient method of using heterosis in beef cattle. In rotational crossbreeding, purebred populations are required only to produce replacement sires; whereas, mating of a terminal sire breed with specific first cross (F_1) females would require much larger purebred populations to supply replacements of the crossbred females. Rotational crossbreeding systems use purebred sires and crossbred cows so that any superiority of parent breeds due to interaction between genes occupying different chromosomal locations (epistasis) is maintained at a higher level than if both parents were crossbred. Part of any superior epistatic combinations accumulated within breeds through long-term natural selection or through deliberate selection will be lost in crosses among breeds because of random recombination of genes. If heterosis is due solely to dominant genetic effects, and epistatic effects are of little consequence, then appropriate outcrossing may be used to correct quickly accumulated mild inbreeding depression and to achieve a desired combination of additive breed effects in either sire or maternal breeds. The potential usefulness of breed improvement through such selective outcrossing would depend heavily upon what proportion of the initial increased heterozygosity from outcrossing is retained in future generations. Thus multibreed composites involving the use of crossbred males and females could compare favorably in efficiency with rotation crossbreeding if epistatic effects were negligible. However, if loss of epistatic superiority is important, composites would have less advantage in performance over the parent breeds, and their justification would rest more upon the need for rapid change in combinations of traits and prospects for faster response to selection.

Procedure

This study involved data from 1,909 progeny representing purebred Angus and Hereford ($\bar{P}$), their reciprocal F_1 crosses, backcrosses ($\bar{B}$) of F_1 females to Angus and Hereford sires, *inter se* matings of unselected F_1 males and females to produce the F_2 generation, and *inter se* matings of unselected F_2 males and females to produce the F_3 generation. The combinations of Angus and Hereford were used to estimate average individual, maternal, and grandmaternal breed effects, individual heterosis, maternal heterosis, and dominance and epistatic genetic effects. Heterosis expressed in the individual (h^I) can be estimated from comparisons of $\bar{F}_1$ and parental purebreds ($\bar{P}$) as, $h^I = \bar{F}_1 - \bar{P}$. Maternal heterosis ($h^M$) is the advantage of F_1 crossbred cows over parental purebred cows in characteristics observed in their progeny. It can be estimated from the parental, F_1, F_2, and backcross means as, $h^M = (\bar{B} + \bar{F}_2 - \bar{F}_1 - \bar{P})/2$, if epistatic effects are ignored.

Results

Means of parental, F_1, backcross, F_2, and F_3 mating types and estimates of genetic effects are presented in Table 1. Calving date includes the influences of conception date and gestation length among mating groups with identical breeding seasons. Survival is percentage weaned of calves born. Pregnancy is conception rate among all yearling heifers exposed to bulls.

The differences among specific mating types [e.g., purebred Angus (A), Hereford (H), reciprocal crosses (AH and HA) and backcrosses (A × HA, H × HA, A × AH, H × AH), though not shown in Table 1, were used to estimate individual, maternal, and grandmaternal breed effects. Average individual breed effects indicate that Angus, compared with Hereford, had calves that were born earlier and had lighter birth weights, lower pre- and postweaning gains, and lower pregnancy rates. Angus also produced lighter carcasses with more fat cover and marbling. Maternal effects were in the direction of reduced birth weight, higher preweaning but lower postweaning growth rate, and increased fatness for Angus contrasted with Hereford. There was a tendency for opposite direction of maternal and grandmaternal effects for preweaning survival and weight gain.

Total heterosis (i.e., $h^I + h^M$) was significant for earlier calving date, heavier birth weight, preweaning and postweaning gain, and heavier and fatter carcasses. The negative heterosis for survival may have resulted from the positive effect of heterosis on birth weight as well as the high average survival rate of Herefords. Other research has shown positive heterosis effects for survival averaging about 3.4 and 1.3 percent for individual and maternal heterosis, respectively. Heterosis in advanced generations of *inter se* mating involves the sum of retained individual and maternal dominance and loss of epistatic effects. For two breeds, heterosis retention stabilizes in the F_3 generation for dominance or independently segregating loci. Thus, heterosis retention is $\bar{F}_3 - \bar{P} = (h^I + h^M)/2$ for two breeds when epistatic effects are of no consequence. Estimates of the percentage of heterosis retained [$100\ (\bar{F}_3 - \bar{P})/(h^I + h^M)$] are given at the bottom of Table 1. Heterosis retained in the F_3 generation did not deviate markedly from the expected 1/2 except for survival, 470-day weight, pregnancy, and marbling score. The values for survival and marbling score are likely inflated unduly by small errors in estimating heterosis effects with values near zero. Except for survival, pregnancy, and marbling, the estimates of heterosis retained are favorable for composite formation.

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[2]For a detailed description of the study reported here, see Journal of Animal Science 60:1117-1132, 1985.

Table 1.—Mating type means and estimates of average breed and heterosis effects

Item[a]	Calving date, julian	Birth weight, lb	Survival, pct	Wean weight, lb	470-day weight, lb	Pregnant, pct	Carcass weight, lb	Fat cover, in	Rib eye area, in^2	Marbling score
Purebred	100.9	67.9	95.4	401	992	87.2	604.5	.55	10.8	5.4
F_1	99.8	69.7	94.7	416	1,027	92.6	629.9	.63	11.5	5.4
Backcrosses	99.0	70.1	94.5	437	1,028	90.7	630.1	.63	11.3	5.4
F_2	96.5	69.4	94.7	437	1,035	86.9	638.7	.63	11.3	5.4
F_3	98.8	69.7	92.3	422	1,035	86.1	631.0	.59	11.3	5.3
Breed effects										
Individual	−5.4**	−5.7**	−3.4	−23.8**	−67.5**	−9.6†	−28.2**	.09**	−.06	.66**
Maternal	−1.8	−.4	−1.4	48.5**	26.9**	−1.8	17.2†	.06*	.19	−.04
Grandmaternal	.4	.0	3.0†	−11.5**	4.4	2.2	4.0	−.03†	.00	.00
Heterosis										
Individual	−1.1	1.8**	−.7	15.2**	35.1**	5.4†	25.1**	.05**	.62**	.04
Maternal	−3.0**	1.1*	−.3	28.2**	22.5**	−1.6	18.1**	.04**	.08	.06
Heterosis, retained, percent	53	65	260	48	75**	−31	61	44	66	−36

[a]Breed effects are the mean differences, Angus minus Hereford.
†P<.10.
*P<.05.
**P<.01.

Germ Plasm Utilization in Beef Cattle

Keith E. Gregory, Larry V. Cundiff, Robert M. Koch, Donald D. Lunstra, and W. Gordon Hays[1]

Introduction

Heterosis achieved through well-organized crossbreeding systems can be used to increase weight of calf weaned per cow exposed to breeding by more than 20 percent. Comprehensive programs of breed characterization have revealed large differences among breeds for most biological traits of economic importance. Because of the high percentage of beef cattle in the U.S. and globally that are in herds too small to use well-organized crossbreeding systems on a self-contained basis, and because of the wide fluctuation in breed composition between generations in rotational crossbreeding systems, there is need for experimental evaluation of the potential of composite populations as an alternative, or, as a supplement to continuous crossbreeding systems to use heterosis, and, to use genetic differences among breeds for optimizing such biological characters as growth rate and mature size, milk production level, lean-to-fat ratio, and climatic adaptability. The primary objective of achieving and maintaining optimum breed composition is to synchronize cattle genetic resources with the production environment most favored by economic and technological factors and with market requirements.

The situation

More than 55 percent of the national beef breeding herd, involving 92 percent of the farms and ranches that have beef breeding cows, is represented by herds that have 100 or fewer cows. Organized crossbreeding systems favor herd size of 100 or more cows. The problem of achieving and maintaining the most optimum contribution by each breed used in rotational crossbreeding systems is reflected by the fact that in a two-breed rotation system, in each generation 66.7 percent of the genes are from the breed of the sire and 33.3 percent of the genes are from the breed of the maternal grandsire at equilibrium (7 generations); and in a three-breed rotation system, in each generation 57 percent of the genes are from the breed of the sire, 29 percent of the genes are from the breed of the maternal grandsire, and 14 percent of the genes are from the breed of the maternal great grandsire at equilibrium (7 generations). If the optimum contribution to achieve maximum adaptability to the production situation should be 25 percent for a specific breed, the optimum is approached infrequently in rotational crossbreeding systems.

Retention of initial heterozygosity following crossing (F_1) and subsequent random mating within the crosses (*inter se*) is a function of the number of breeds and the proportion each breed contributes to a composite population. Retention of initial (F_1) heterozygosity is proportional to $1 - \sum_{i}^{n} P_i^2$, where P_i is the fraction of each of *n* breeds in the pedigree of a composite population; e.g., three breed composite formed from 3/8 breed A, 3/8 breed B, and 1/4 breed C $= 1 - [(3/8)^2 + (3/8)^2 + (1/4)^2] = .656$. Where the breeds contribute equally to the foundation of a composite population, retention of initial heterozygosity following crossing can be computed $\frac{n-1}{n}$ where *n* is the number of breeds contributing *equally* to the foundation of a composite population; e.g., four breed composite formed from 1/4 breed A, 1/4 breed B, 1/4 breed C, and 1/4 breed D $= 3/4 = .75$. The loss of heterozygosity occurs between the F_1 and F_2 in populations mated *inter se*. Thus, for maternal traits, performance of the F_2 is evaluated through their F_3 progeny.

Computations of heterozygosity retained in different mating types and estimates of the increase in weight of calf weaned per cow exposed to breeding as a result of heterosis are presented in Table 1. These estimates of heterosis are appropriate *if* retention of heterosis is proportional to retention of heterozygosity in composite populations. As indicated by Table 1, the percentage of F_1 heterozygosity retained in composite populations based on approximately equal contribution by either three or four breeds is equal to, or exceeds, the percentage of F_1 heterozygosity retained in a continuous two-breed rotational crossbreeding system after equilibrium is reached. A primary objective of this project is to determine experimentally if retention of heterosis in composite populations is proportional to retention of heterozygosity.

Research results from rotational crossbreeding systems have shown that retention of heterosis is approximately equal to retention of heterozygosity and, thus, production increases as a result of heterosis can be estimated with precision for different crossbreeding systems if the level of heterosis for the traits of interest is known.

Research objectives

Specific research objectives of the Germ Plasm Utilization Project are: (1) Determine the percentage of initial heterosis that is retained in composite populations; i.e., to what extent is retention of heterosis proportional to retention of heterozygosity; (2) Determine the additive genetic variance, particularly for traits contributing to reproductive performance, in composite populations relative to parental purebred populations contributing to the composites; i.e., *is* selection for male and female reproductive traits more effective in composite populations than in the contributing purebreds; (3) Develop effective selection criteria and procedures to improve both male and female reproductive performance in beef cattle; (4) Determine the feasibility of developing new populations of beef cattle based on a multi-breed (composite) foundation as an alternative to rotational and other crossbreeding systems to utilize heterosis; and (5) Determine the feasibility of using genetic differences among breeds for making more rapid progress toward optimizing such biological characters as (a) climatic adaptability, (b) growth rate and mature size, (c) carcass composition, and (d) milk production.

Procedure

The calving schedule shown in Table 2 involving F_1, F_2, F_3, and purebred calving females will provide the basic data essential for: (1) estimating linearity of association of heterosis with heterozygosity in composite populations; (2) estimating genetic and phenotypic parameters in order to determine selection response, particularly for traits contributing to fitness, in both composite and purebred populations; and (3) developing selection criteria and procedures for both male and female reproductive phenomena. As indicated by Table 2, F_1, F_2, F_3, and contributing purebreds produce calves in the same seasons. These contrasts provide the basis for estimating heterosis and for determining heterosis retention from the F_1 to the F_2 for reproductive and maternal traits by comparing F_1 and F_2 and their progeny with each other and with appropriate parental purebreds.

Matings for the period from 1985 through 1989 (Table 2) will be consistent with the procedures that have been followed in this project; i.e., yearling heifers will be mated by natural service to yearling bulls for about 45 days and females 2 years old and older will have a breeding season of about 56 days;

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about one-half of the breeding season will be by AI and one-half will be by natural service. All females born will be retained for breeding, and excess females in each population will be removed based on nonperformance criteria; i.e., age, color, atypical anatomy, etc. Open females will not be retained subsequent to the 1985 breeding season. Composite populations were formed from the same genetic base that is represented in the contributing purebred populations.

The intent of the mating plan is to obtain 15-30 female progeny per sire for estimating genetic parameters for the characters of primary interest. Close matings are avoided in all populations to reduce rates of inbreeding.

Results

Results from preliminary data analyses indicate high levels of heterosis for most characters evaluated. Heterosis for paired testicular volume was 13.1 percent, 13.3 percent, and 17.4 percent in the three composite populations. An estimate of heritability of scrotal circumference at 1 year was .41 ± .06. Results from preliminary data analyses indicate that retention of heterosis is proportional to retention of heterozygosity for growth-related traits. Sufficient data have not been accumulated to provide preliminary estimates of heterosis retention relative to heterozygosity for reproduction and maternal traits.

Table 1.—Heterozygosity of different mating types and estimated increase in performance as a result of heterosis

Mating type	Heterozygosity percent relative to F_1	Estimated increase in calf weight weaned per cow exposed[a] (pct)
Pure breeds:	0	0
Two-breed rotation at equilibrium	66.7	15.5
Three-breed rotation at equilibrium	85.7	20.0
Four-breed rotation at equilibrium	93.3	21.7
Two-breed composite:		
F_3 - 1/2A, 1/2B	50.0	11.6
F_3 - 5/8A, 3/8B	46.9	10.9
F_3 - 3/4A, 1/4B	37.5	8.7
Three-breed composite:		
F_3 - 1/2A, 1/4B, 1/4C	62.5	14.6
F_3 - 3/8A, 3/8B, 1/4C	65.6	15.3
Four-breed composite:		
F_3 - 1/4A, 1/4B, 1/4C, 1/4D	75.0	17.5
F_3 - 3/8A, 3/8B, 1/8C, 1/8D	68.8	16.0
F_3 - 1/2A, 1/4B, 1/8C, 1/8D	65.6	15.3
Five-breed composite:		
F_3 - 1/4A, 1/4B, 1/4C, 1/8D, 1/8E	78.1	18.2
F_3 - 1/2A, 1/8B, 1/8C, 1/8D, 1/8E	68.8	16.0
Six-breed composite:		
F_3 - 1/4A, 1/4B, 1/8C, 1/8D, 1/8E, 1/8F	81.3	18.9
Seven-breed composite:		
F_3 - 3/16A, 3/16B, 1/8C, 1/8D, 1/8E, 1/8F, 1/8G	85.2	19.8
Eight-breed composite:		
F_3 - 1/8A, 1/8B, 1/8C, 1/8D, 1/8E, 1/8F, 1/8G, 1/8H	87.5	20.4

[a]Based on heterosis effects of 8.5 percent for individual traits and 14.8 percent for maternal traits and assumes that retention of heterosis is proportional to retention of heterozygosity. These estimates of heterosis were obtained in a crossbreeding experiment involving the Angus, Hereford, and Shorthorn breeds that was started at the Fort Robinson Beef Research Station and completed at MARC. This assumption has *not* been validated for composite populations.

Table 2.—Germ plasm utilization project—estimated number calving females[a]

Breed group	Year					
	1985	1986	1987	1988	1989	1990
1/4C, 1/4B, 1/4L, 1/8H, 1/8A MARC I						
F_1	135	137	116	99	84	71
F_2	69	133	110	100	100	100
F_3		16	44	82	120	120
1/4S, 1/4G, 1/4H, 1/4A MARC II						
F_1	123	108	92	78	66	56
F_2	176	157	110	100	80	79
F_3	17	46	104	120	120	120
1/4R, 1/4H, 1/4P, 1/4A MARC III						
F_1	176	180	150	127	100	84
F_2	40	89	128	120	120	120
F_3			16	44	80	120
Composite total	736	870	870	870	870	870
Hereford (H)	100	90	90	90	90	90
Angus (A)	100	90	90	90	90	90
Limousin (L)	100	90	90	90	90	90
Brown Swiss (B)	100	90	90	90	90	90
Charolais (C)	100	90	90	90	90	90
Gelbvieh (G)	91	90	90	90	90	90
Simmental (S)	100	90	90	90	90	90
Red Poll (R)	100	90	90	90	90	90
Pinzgauer (P)	141	90	90	90	90	90
Purebred total	932	810	810	810	810	810
Grand Total	1,668	1,680	1,680	1,680	1,680	1,680

[a]Females exposed to breeding will be 2,400; i.e., 1,680 calving females and 720 yearling heifers. After 1985 breeding season, open females will not be retained.

Maternal Effects in Four Diverse Breeds of Cattle

Keith E. Gregory, Larry V. Cundiff, and Robert M. Koch[1]

Introduction

Differences between reciprocal crosses are the result of breed differences in prenatal maternal effects and/or breed differences in postnatal maternal effects. Breed differences in postnatal maternal effects are well documented and are mediated through breed differences in milk production and perhaps through other maternal factors. Breed differences in prenatal maternal effects have received less attention by research interests than breed differences in postnatal maternal effects. Breed differences in prenatal maternal effects may be caused by either differences in ovum cytoplasm or by differences in uterine environment or by both. In most reports of experimental results, the prenatal and postnatal components of maternal effects have been confounded, as is the case for the results reported here.

Procedure

This study included 1,207 calves born (625 males and 582 females) in 1973 and 1974 as a result of mating Hereford, Angus, Red Poll, and Brown Swiss females by artificial insemination to Hereford, Angus, Red Poll, and Brown Swiss sires (Table 1).

The Hereford and Angus dams used in this experiment were sampled as calves from commercial producers in western Nebraska. Brown Swiss dams were either purchased as calves from dairy farms in Wisconsin, Iowa, and Minnesota or produced at the U.S. Meat Animal Research Center (MARC). Most of the Brown Swiss dams were of domestic ancestry; however, some were by a Brown Swiss sire imported from Switzerland. Red Poll dams in this experiment were registered purebreds that were either purchased as calves from breeders in Missouri, Illinois, Indiana, Wisconsin, and Texas or produced at MARC. All breed groups of females ranged in age from 4 to 9 years when their progeny were born in 1973 and 1974.

Most sires of each breed were used both years. Hereford, Polled Hereford, Angus, and four domestic Brown Swiss sires used in this study were sampled from among those selected on individual performance data as a basis for entry into the progeny testing programs of commercial AI organizations. Seven Brown Swiss sires had been imported from Switzerland and Germany (dual-purpose), and two Brown Swiss sires were from domestic Brown Swiss dams and by imported Brown Swiss sires. Red Poll sires were sampled from Red Poll breeders in the north central and southern regions of the U.S., with the objective of obtaining a representative sample of the breed. All of these Red Poll sires were being used in purebred Red Poll herds after evaluation for growth rate in the Record of Performance Program of the American Red Poll Association. Progeny test results were not available on any of the sires from any breed at the time they were sampled for use in this program. Dams of each breed were assigned at random to breed of sire and to sires within breed each year of the experiment.

The dams were maintained on improved pasture (April to November) and fed grass and legume hay on pasture during the winter. Calves were born over a 50-day calving season from early March until late April. Average birth date was April 3. All calves were identified and weighed, and male calves were castrated within 24 h of birth. Calves were creep fed whole oats from mid-August until weaning in 1973 and from early August until weaning in 1974. The average amount of creep feed consumed was 46 lb/calf in 1973 and 139 lb/calf in 1974. The calves were weaned October 23 in 1973 at an average age of 203 days. Because of drought conditions, calves were weaned September 17 in 1974 at an average age of 167 days. Creep feed consumption was probably increased in 1974 to compensate for limitations on forage availability.

Females born in both years were mated by artificial insemination (AI) for 42 days, starting May 20 for heifers born in 1973 and May 19 for those born in 1974, followed by a 22-day period of natural service mating. Females born in 1973 were moved from improved cool-season pasture to improved warm-season pasture at the end of the 42-day AI season, and the females born in 1974 were moved from improved cool-season pasture to improved warm-season pasture midway through the AI breeding period. The females were run as one herd except during the 22-day period of natural service mating after the 42-day AI breeding season when they were run in two herds. In both years, the females remained on improved warm-season pasture until October.

In both years, females were weighed at about 28-day intervals from weaning until they were turned on to improved cool-season pasture. The females were weighed at the end of the natural service breeding season at an average age of about 470 days and again on September 30 for the heifers born in 1973 and on October 6 for those born in 1974 when they were palpated for pregnancy and measured for hip height at an average age of about 550 days.

The steers produced in 1973 were slaughtered serially at average ages of 423, 451, and 485 days for an average slaughter age of 453 days for all steers. The steers produced in 1974 were slaughtered serially at average ages of 421, 449, and 485 days for an average slaughter age of 452 days for all steers. Steers were assigned to slaughter schedule at random within breeding group. About one-third of each breeding group on which carcass data were analyzed were slaughtered at each date in the serial slaughter schedule for each year.

The steers were weighed without shrink and transported to a commercial cattle abattoir where they were slaughtered and chilled by standard procedures. The carcass data were obtained after a chill period of about 24 h. Standard procedures were used to obtain objective measures and in subjective evaluations of the traits for which data were collected and analyzed.

Multiple regression equations were used to estimate cutability (pct), retail product (pct), retail product weight (lb), fat trim (lb) and bone (lb).

[1]Gregory is the research leader, Production Systems Unit; Cundiff is the research leader, Genetics and Breeding Unit, MARC; and Koch is a professor of animal science, University of Nebraska-Lincoln, stationed at MARC.

Table 1.—Experimental design showing number of calves produced by subgroup

	Sires and number of offspring									
	Red Poll		Brown Swiss		Hereford		Angus		Total	
Dams	Born	Weaned	Born	Weaned	Born	Weaned	Born	Weaned	Born	Weaned
Red Poll	39	37	45	41	46	41	48	47	178	166
Brown Swiss	21	19	33	26	28	27	30	29	112	101
Hereford	93	89	123	121	86	83	103	99	405	392
Angus	121	119	139	133	126	123	126	117	512	492
Total	274	264	340	321	286	274	307	292	1,207	1,151

Results

Differences between reciprocal crosses are presented in Table 2 for preweaning traits, in Table 3 for growth rate and puberty of females, in Table 4 for growth traits of steers, and in Table 5 for carcass traits of steers. Differences between reciprocal crosses of two breeds include prenatal and postnatal maternal effects as well as any differences in average additive direct genetic effects between the sample of sires and of dams represented in the reciprocal crosses (e.g., H♂ x A♀ *vs* A♂ x H♀).

Calves with Angus dams in crosses with Hereford and calves with Brown Swiss dams in crosses with Red Poll did not differ from reciprocal crosses in birth weight but gained significantly faster preweaning and were significantly heavier at weaning. Calves with Angus dams in crosses with Hereford and calves with Brown Swiss dams in crosses with Red Poll gained at a slower rate postweaning than reciprocal crosses of both sexes so that little or no difference was observed between these reciprocal crosses in 550-day weight of females, 424-day weight of steers and slaughter weight, carcass weight, estimated retail product weight, estimated fat trim weight, and estimated bone weight of steers. Thus, calves with Hereford dams in crosses with Angus and calves with Red Poll dams in crosses with Brown Swiss compensated during the postweaning period for their slower growth rate than reciprocal crosses during the preweaning period (Tables 2, 3, 4, and 5).

Generally, calves with Red Poll and Brown Swiss dams in crosses with Hereford and Angus were heavier than reciprocal crosses at birth and at weaning and in weights and heights postweaning; steers had heavier slaughter weight, carcass weight, estimated retail product weight, estimated fat trim weight, and estimated bone weight (Tables 2, 3, 4, and 5). Calves with Red Poll and Brown Swiss dams in crosses with Hereford and Angus had postweaning gains that averaged approximately the same as gains of the reciprocal crosses. For females, the reciprocal difference involving these crosses averaged 74 lb at weaning and averaged 61 lb at 550 days; for steers, the reciprocal difference involving these crosses averaged 78 lb at weaning, 84 lb at 424 days, and 81 lb at slaughter (453 days) and produced carcasses that were 49 lb heavier. Thus, there was no weight gain compensation for calves with Red Poll and Brown Swiss dams in crosses with Hereford and Angus during the postweaning period; the magnitude of the difference in favor of the reciprocal crosses with Red Poll and Brown Swiss dams in crosses with Hereford and Angus was approximately the same at yearling age as at weaning.

The lack of difference in composition of gain between the reciprocal crosses with Red Poll and Brown Swiss dams in crosses with Hereford and Angus is reflected by no difference between these reciprocal crosses in estimated cutability (pct) and estimated retail product (pct, Table 5). Thus, the weight increase in favor of the reciprocal cross steers with Red Poll and Brown Swiss dams in crosses with Hereford and Angus was proportional in regard to lean, fat, and bone tissue.

Table 2.—Differences between reciprocal crosses - preweaning traits

Reciprocal crosses[a]	Birth weight (lb)	Calving difficulty (pct)	Calf crop weaned (pct)	Average daily gain (lb)	200-day weight (lb)
BR minus RB	1.3	19.8**	.7	–.16**	–31**
HR minus RH	2.9	7.9	–6.3	.26**	55**
AR minus RA	5.3**	1.7	.3	.24**	52**
HB minus BH	8.8**	–12.8*	–1.9	.50**	110**
AB minus BA	4.4*	–5.4	1.1	.43**	90**
AH minus HA	–.9	–1.6	–1.6	–.12**	–26**

[a]R = Red Poll, B = Brown Swiss, H = Hereford, A = Angus. Sire breed listed first.
*P <.05.
**P<.01.

These results show that increased weight gains associated with maternal effects during the prenatal and the postnatal preweaning periods and reflected at slaughter do not have the same effect on composition of the increased weight gain as does a higher nutritive environment provided during the growing-finishing period through increased dietary energy density. Results from research conducted at MARC have shown that increasing the dietary energy density beyond 2.6 to 2.7 Mcal ME/kg during the growing-finishing period will result in increased weight gain but that more than 80 percent of the increased weight gain is the result of increased carcass fatness. Thus, it is concluded that either the nutritive environment associated with maternal effects (prenatal and postnatal) has an influence on composition of increased weight gain different from that of the nutritive environment associated with growing-finishing dietary regimen, or that the effect of dietary regimen on composition of increased weight gains may be different if administered before the growing-finishing period.

These results show that the maternal effect on growth rate for some breed crosses starts prenatally and is reflected by increased birth weight (Table 2), is accelerated during the preweaning period, and is of about the same magnitude at yearling as at weaning (Tables 2, 3, and 4). Prenatal and postnatal maternal effects and their persistence, at least to yearling age, are particularly relevant in considering breed of recipient effects on calves produced by embryo transfer.

These results suggest that breeds that have been selected for milk production (Red Poll and Brown Swiss) in crosses with breeds that have not been selected for milk production (Hereford and Angus) show maternal effects of a different nature in regard to prenatal growth rate and postweaning compensation for differences in preweaning growth rate than do reciprocal crosses among breeds where selection criteria for milk production have been similar; e.g., Red Poll with Brown Swiss or Hereford with Angus. The biological basis for this interesting phenomenon is not apparent.

Table 3.—Differences between reciprocal crosses - growth rate and puberty in females

Reciprocal crosses[a]	200-day weight (lb)	400-day weight (lb)	500-day weight (lb)	550-day hip height (in)	Weight at puberty (lb)	Age at puberty (days)	Pregnant 550 days (pct)
BR minus RB	–43*	–32	–10	–.51	–14	17	12
HR minus RH	56**	63**	45**	.28	60**	2	–5
AR minus RA	50**	52**	58**	.79**	58**	11	2
HB minus BH	102**	89**	71**	1.06**	53**	–26*	–5
AB minus BA	86**	73**	71**	1.38**	42**	–27*	–10
AH minus HA	–36**	–28*	0	.47	4	22*	18

[a]R = Red Poll, B = Brown Swiss, H = Hereford, A = Angus. Sire breed listed first.
*P<.05.
**P<.01.

MARC has an experiment in progress to determine, by use of embryo transfer involving reciprocal crosses of the Brown Swiss and Hereford breeds and reciprocal crosses of the Red Poll and Angus breeds, the relative contribution of differences in ovum cytoplasm and differences in uterine environment in contributing to prenatal maternal effects. Further, the relative contribution of prenatal and postnatal maternal effects to total maternal effects are being determined by early weaning one-half of the calves from these matings and allowing the other one-half of the calves to remain on their dams to an age of about six months. The results from the experiment reported here stimulated the interest to conduct the experiment to determine the relative contribution of prenatal and postnatal factors to total maternal effects and to determine the relative contribution of ovum cytoplasm and uterine environment in contributing to prenatal maternal effects.

Table 4.—Differences between reciprocal crosses - growth traits of steers

Reciprocal crosses[a]	200-day weight (lb)	312-day weight (lb)	424-day weight (lb)
BR minus RB	–23	–6	17
HR minus RH	52**	56**	56**
AR minus RA	56**	74**	86**
HB minus BH	111**	111**	70**
AB minus BA	92**	86**	125**
AH minus HA	–14	–10	12

[a]R = Red Poll, B = Brown Swiss, H = Hereford, A = Angus. Sire breed listed first.
**P<.01.

Table 5.—Differences between reciprocal crosses - carcass traits of steers

Reciprocal crosses[a]	Slaughter weight, 453 days (lb)	Carcass weight (lb)	Est. cut.[b] (pct)	Est.[b] retail product (pct)	Est.[b] retail product (lb)	Est.[b] fat trim (lb)	Est.[b] bone (lb)
BR minus RB	42	19	1.3	1.5	21	2	2
HR minus RH	52**	32**	–.6	–.7	15	9*	4**
AR minus RA	76**	48**	–.8	–1.0	23**	14**	5**
HB minus BH	75**	51**	–.4	–.4	28**	10*	6*
AB minus BA	121**	65**	–.7	–.9	35**	16**	8**
AH minus HA	21	6	–.1	–.2	3	2	0

[a]R = Red Poll, B = Brown Swiss, H = Hereford, A = Angus. Sire breed listed first.
[b]Est. = estimated; cut. = cutability.
*P<.05.
**P<.01.

Twinning in Cattle

Sherrill E. Echternkamp, Keith E. Gregory, W. Gordon Hays, Larry V. Cundiff, and Robert M. Koch[1]

Introduction

The economic benefits of increasing reproductive rate indicate a need to determine the feasibility of increasing the frequency of twinning in cattle, either by selection or by an artificial method. Rate of reproduction has a major impact on life cycle costs of production for different meat animal species and, thus, upon the production resources for which different species are competitive. For example, the average beef cow is capable of producing about .7 of her body weight per year in progeny market weight, but the comparable multiple is 8 in pigs and more than 70 in meat chickens. The objectives of this project focus on gaining the understanding needed to develop a technology for increasing the frequency of twinning in cattle. A comprehensive physiological examination of cows that produce a high frequency of twins may establish the biological and/or environmental requirements for multiple births in cattle and the feasibility of increasing twinning frequency by selection, artificial induction, or by both. This experiment is being conducted to provide understanding relating to these considerations. Specific objectives of the experiment are: (1) determine the effectiveness of selection for multiple births in cattle; (2) develop and evaluate selection criteria for multiple births in cattle; (3) accumulate data that will contribute to an economic assessment of multiple births in cattle for varying resource situations; (4) establish husbandry requirements for herds of cattle that have a high twinning frequency; (5) determine the relative importance of multiple ovulation and embryo survival in contributing to multiple births in cattle in both spring and fall breeding; and (6) determine the usefulness of cows with high twinning frequency as "models" to gain understanding of biological factors that relate to embryo survival for both single and multiple births in cattle.

Procedure

Cows that have a high estimated breeding value for twinning have been acquired from private breeders and have been provided by cattle populations in other research projects at the Research Center. Emphasis has been on acquiring cows from breeds that are believed to have a relatively high twinning frequency; i.e., Holstein, Simmental, Brown Swiss, Charolais, Gelbvieh, Pinzgauer, and Shorthorn. Twinning frequency for these breeds is believed to average in the range of from 3.0 to 4.5 percent. Because of numbers available and because of the complete records available in many dairy herds, Holsteins have been acquired in a greater frequency than any other breed.

A program of superovulation and embryo transfer is used to increase number of progeny of cows that have highest estimated breeding value for twinning. The procedure is to include about 25 cows with highest estimated breeding value for twinning for two superovulation and embryo transfer cycles in each year (May and September). Cows included in the superovulation and embryo transfer program (donors and recipients) are exposed to breeding in the subsequent spring or fall breeding season. It is expected that about 100 calves will be produced by embryo transfer each year. Recipient females for the embryo transfer program are heifers and cows in the twinning project that have relatively low estimated breeding value for twinning.

Total number of breeding age females in the twinning project is 900. About 300 females are produced in the project each year, and they replace females that have lower estimated breeding value for twinning.

Females from breeds that have a relatively high twinning frequency (Simmental, Brown Swiss, Charolais, Gelbvieh, and Pinzgauer) in other projects at the Research Center are placed in the twinning project immediately after production of their first set of twins, provided such action is compatible with the objectives of the effort in which they have been involved. The age limit on cows handled in this manner is three years.

Females in the twinning project are mated to males that have a relatively high estimated breeding value for twinning. We have imported semen from three Swedish Friesian bulls and from two Norwegian Red bulls whose daughters have twinned at a high frequency (about 10 percent).

Within the framework of achieving near maximum selection intensity for twinning frequency in the males used, matings are made in a manner so as to achieve and maintain a high level of heterozygosity in each animal produced in the twinning project and a milk level that is in general harmony with achieving postpartum intervals of no more than 60-70 days when cows are maintained in an environment appropriate for a high beef production response capability. An effort is made to limit the contribution of any breed to 30-35 percent in the resulting composite population.

About 20 percent of males that have highest estimated breeding value for twinning are retained intact and developed for potential use as sires.

Cows that produce a high frequency of multiple ovulations and births are utilized as experimental models to obtain basic physiological information relating to ovulation, embryo survival, and postpartum reproduction. Ovulation rate is determined both by rectal palpation of corpora lutea and by laparoscopy. Experiments predominantly focus on comparison of hypothalamic-pituitary-ovarian relationships between multiple and single ovulating cows. The role of the endocrine system in the regulation of ovulation rate and embryo survival is assessed in single and multiple ovulating cows through the establishment of hormone secretion profiles for both ovarian (estrogen, inhibin, progesterone, etc.) and pituitary (FSH, LH, prolactin, oxytocin) hormones, and through morphological and biochemical evaluations of follicular development and corpus luteum function. In addition, experiments are conducted to study uterine-embryo interactions and how these interactions are affected by number of embryos. We have observed a higher twinning frequency in fall relative to spring calving; the relative contribution of ovulation rate and embryo survival to this difference is being determined.

Results

A summary of preliminary results from the twinning project is presented in Table 1 and suggests the following.

Cows that have a history of producing twins either in private herds or at the Research Center continue to produce twins at a high frequency in this project; i.e., 18.3 percent twinning frequency subsequent to producing two sets of twins and 14.5 percent twinning frequency subsequent to producing one set of twins. Over all ages, normal twinning frequency of the breeds included in this project averages between 3.0 and 4.5 percent.

Daughters of cows that have produced two or more sets of twins produce twins at a frequency (8.1 percent) more than eight times as great as females of the same age and from the same breeds at the Research Center where selection for twinning has not been practiced. Twinning frequency is much lower in females producing their first and second calves than in adult females.

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Table 1.—Summary of preliminary results from twinning project (includes fall calving in 1984)

Records when purchased (cows purchased in 1976, 1977, 1981, and 1982)

No. cows	No. parturitions	No. sets twins	Twinning frequency (pct)	No. sets twins per cow
113	437	295	67.50	2.61

Records since purchased and records of Research Center cows subsequent to producing two sets of twins

No. parturitions	No. sets twins	Twinning frequency (pct)
219	40	18.3

Records of daughters of cows with two or more sets of twins

No. parturitions	No. sets twins	Twinning frequency (pct)
284	23	8.1

Records on cows put in project after producing one set of twins

No. parturitions	No. sets twins	Twinning frequency (pct)
207	30	14.5

Breeding Cattle for Genetic Resistance to Disease

Roger T. Stone and Larry V. Cundiff[1]

Introduction

For many hundreds of years cattle with the greatest resistance to disease have probably survived to leave more offspring in succeeding generations than those less resistant to disease. Resistance to disease also may have increased indirectly through a favorable association with other characteristics, such as growth rate or milk yield, which have received major emphasis in genetic improvement programs in cattle. However, except for some selection against mastitis in dairy cattle, genetic resistance to disease has not received direct emphasis in genetic improvement programs. Greater understanding of biological mechanisms involved in disease resistance could lead to more effective selection of breeding stock.

Evidence for Genetic Resistance to Specific Diseases in Cattle.

Survival. Calf mortality adds significantly to costs of beef production, and some of the costs are related to disease. In one review of scientific literature, survival from birth to 6 to 9 months of age averaged 91 percent in 24 beef cattle experiments and 80 percent in 11 dairy cattle experiments. Significant genetic variation exists among breeds for survival, much of which is associated with variation in birth weight and calving difficulty. Within breeds, heritability (the proportion of superiority of selected parents which is passed on to offspring) of survival from birth to weaning is low and tends to be greater when treated as a trait of the dam (8 pct) than when treated as a trait of the offspring (4 pct). When the large number of causes of mortality are considered, it is not surprising that heritability of survival (pct dead or alive) is low.

Although heritability of survival is low, effects of heterosis (superiority of crossbreds relative to purebreds) on survival are relatively large and important. Averaged over many experiments, calf-crop percentages weaned are increased by 3.4 percent by effects of individual heterosis on survival of crossbred calves and by an additional 1.3 percent by effects of maternal heterosis on the survival of calves raised by crossbred dams. The generally consistent estimates of heterosis among experiments and among years suggest that resistance to a number of stresses associated with mortality is greater in crossbreds than in purebreds. Evidently, extra gene combinations carried by crossbred individuals compared to purebred individuals are responsible for this advantage.

Longevity. Significant effects of heterosis have also been found on longevity in beef cattle (see article in this report entitled "Effects of Heterosis on Longevity"). Effects of heterosis increased average longevity of F_1 cows by 1.36 years (16 pct) over that of straightbred Hereford, Angus, and Shorthorn cows. Significant differences were also found among breeds for longevity. (In that study Angus lived significantly longer than Shorthorns.) Also, some of the variation among breeds in longevity was associated with genetic resistance to disease. For example, the four cows removed from the long-term experiment because of cancer eye were all Herefords. (Cancer eye susceptibility is known to be a highly heritable component of longevity.)

Tropical environmental factors. Australian researchers in the Division of Tropical Animal Science, CSIRO, have demonstrated that *Bos indicus* cattle (e.g., Brahman, Sahiwal) and *Bos indicus* x *Bos taurus* crosses are significantly more resistant to ticks than *Bos taurus* breeds and crosses (e.g., Shorthorn, Hereford, and Hereford x Shorthorn crosses). *Bos indicus* breeds are also significantly more resistant to internal parasites (gastrointestinal helminths), high ambient temperature and solar radiation, pinkeye disease, and nutritional stress than *Bos taurus* breeds. They have also found resistance to ticks to be highly heritable and, consequently, responsive to selection. In one experiment, after just three generations of selection, resistance to ticks increased from 89 to 99 percent in an Australian Illawarra Shorthorn herd. Resistance to ticks was determined from the average percent mortality of female ticks from two artificial infestations of 20,000 larvae, 14 days apart. An immune response to infestation is involved in determining levels of genetic resistance to ticks.

Mastitis. Dr. Robert Miller at the Beltsville Agricultural Research Center, Beltsville, Maryland (USDA, Agricultural Research Service) has estimated that losses due to mastitis add $2 billion annually to the cost of milk production in the U.S. Resistance to mastitis is 10 to 20 percent heritable. A possible association between the bovine major histocompatibility genotype (BOLA) and mastitis susceptibility has been demonstrated by European scientists (Solbu and Li in Norway and Spooner in Scotland). The major histocompatibility system is comprised of a block of genes regulating the immune response in all animal species, and it has been implicated in resistance to disease in humans, chickens, rats, and mice, as well as cattle. In cattle, indications were that one BOLA gene (type W_2) was associated with high resistance to mastitis while another gene (W_{16}) was susceptible to the disease.

Bloat. Genetic resistance to bloat is being investigated by scientists at the Ruakura Agricultural Research Station, Ministry of Agriculture and Fisheries, Hamilton, New Zealand. A foundation herd was divided into 37 highly (HS) and 32 lowly (LS) susceptible cows on the basis of scores ranging from 0 to 4, where 0 represented no visible bloat, 1 = mild bloat, 2 = moderate bloat, 3 = severe bloat, and 4 = dangerous bloat. Friesian and Jersey bulls that were progeny tested for high (HS) and low (LS) susceptibility were used in the respective herds for four years, after which the HS and LS herds were closed. At 2 years of age, the second generation animals in the LS herd had a mean score of .91 and those in the HS herd had a mean score of 2.64, indicating rapid effects of divergent selection. Eleven salivary proteins have also been separated and quantified. Two appear to be positively correlated with bloat, and two appear to be negatively correlated with bloat. This would suggest that the susceptibility of bloat can be determined without producing clinical symptoms.

General Disease Resistance

There are a number of examples of successful selection for resistance to specific diseases in animal species, such as mice and chickens. However, because of the large number of diseases, successful selection for simultaneous resistance to many diseases in animals is impossible, especially if appropriate attention is to be given to other important production characteristics. Thus, there is a need to develop procedures to select for general disease resistance.

Immunoglobulins. For immunity to many pathogens, young calves are dependent on immunoglobulins passively received from their dams in colostrum. Scientists at Oregon State University, working in cooperation with MARC, have found that significant genetic variation exists among and within breeds of cattle in the ability to absorb colostrol antibodies. In one experiment, breed rankings were Angus, Red Poll, and Hereford for immunoglobulin (IgG_1) concentrations. In another experi-

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ment, calves from MARC Hereford lines (selected for weaning weight, yearling weight, or an index of yearling weight and muscling score) were lower in IgG_1 concentration than calves from an unselected control line. The IgG_1 levels in the selected lines were associated with increased birth weight and, in cows calving at young ages, calving difficulty, and calf mortality. Average estimates of heritability were 9 percent for IgG_1 concentration considered as a trait of the calf and 14 percent when it was considered as a trait of the dam.

Antigen-antibody response. Perhaps the most encouraging evidence that selection for disease resistance may be effective comes from experiments with mice on selection for immunoresponsiveness which have been conducted by scientists at the Curie Institute in Paris, France. Mice were selected for high-*vs* low-peak antibody titers after immunization using five different regimens that involved a variety of complex natural immunogens (i.e., red blood cells from sheep or pigeons; Salmonella, bovine serum albumin, or rabbit gamma globulin). Divergence of high *vs* low lines was significant in every case, and heritability estimates were 20 to 22 percent. Not only was immune response to the specific natural immunogens changed by selection, but immune response to a variety of other bacterial and parasitic infections was related to genetic changes resulting from selection. A high response line was more resistant to infections (e.g., *P. berghei, T. cruzi, N. dubius, Rabies* virus and *T. spiralis)* dependent on one protective mechanism (antibody dependent immunity), while a low response line was more resistant to infections (e.g., *S. typhimurium, Y. pestis, B. abortus suis, L. tropica* and *S. mansoni)* dependent on another protective mechanism (macrophage dependent or cellular immunity). In most cases, the line that was spontaneously more resistant also was protected to a higher degree by vaccination.

These results are somewhat discouraging from the point of view of selection for resistance to disease in a single population. Selection for resistance to a specific infection may lead to resistance to one group of infections but high susceptibilty to other types of infection. In beef cattle, perhaps this complication can be overcome by use of crossbreeding systems that exploit heterosis and choice of breeds that complement each other when crossed. With the aid of vaccination procedures to maintain parental seedstock populations, it may be possible to select for one type of disease resistance in sire breeds and another type of disease resistance in maternal breeds. If so, genetic resistance to disease could be realized in crossbred animals produced by mating complementary maternal and sire breeds.

Research Approach at MARC

From the above discussion, it is likely not practical to select for resistance to one disease after another without compromising other desirable traits. Further, for many diseases it would be prohibitively expensive to select for resistance by experimentally infecting groups of cattle. At this point in time, the most viable approach to identifying resistant or susceptible animals is to define simple genetic markers that are associated with, or linked, to the very complex genes controlling disease resistance. The potential usefulness of such an ideal marker is exemplified in the following hypothetical case: It is determined that animals which are type A for this marker are four times less likely to contract pneumonia under feedlot conditions than those which are type B for this hypothetical marker. Thus, a bull calf that is type A would, in all likelihood, be selected to keep as a sire over another that is type B.

Recent advances in immunogenetics and molecular biology have made it feasible to identify simple genetic markers and polymorphisms and to determine their relationship to disease in cattle. The field of immunogenetics is mainly centered around the major histocompatibility complex, which is a series of polymorphic cell surface antigens that are divided into either class I or class II antigens. The presence or absence of certain class I antigens have been found to be associated with numerous human diseases and possibly with tick resistance and mastitis in cattle. There are fewer different class II antigens, however. Different types of these antigens are associated with the overall immune response. Advances in molecular biology have provided the research tools necessary to detect minor variations in the base sequences in DNA between animals. These sequence variations are also inherited as simple genetic markers and certain ones have been identified as useful markers in predicting the occurrence of human diseases (e.g., Huntington's disease).

The overall goal of a program to define relationships between simple genetic markers and diseases in cattle has a major difference if compared to a similar program in humans. That is, very rare diseases and those occurring after reproductive age are of minor concern in cattle but are very important in humans. Thus, we feel that our research efforts should be directed toward overall immune responsiveness since the most common denominator in many cattle losses is opportunistic infections brought about by stresses. Unfortunately, this dictates that we will not have a large data base from laboratory species or humans from which to work. Our current and future efforts are to combine the disciplines of molecular biology, immunogenetics, and epidemiology to define simple genetic markers and their relationships to disease resistance.

Animal and Forage Response to Short-Duration Rotational Grazing

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Introduction

It has recently been suggested that the use of a short-duration rotational grazing (SDG) system can significantly increase total beef production on rangelands. The periodic intense grazing pressure of the SDG system is assumed to retard maturation of the forage and stimulate forage growth. This combination of immature, high quality forage and greater total forage production should allow higher stocking rates and/or improved animal performance. Such a system may be of greater utility with improved pastures planted to forages possessing a greater genetic potential for growth. This study was designed to determine the animal and forage responses to SDG on a cool-season improved pasture compared with a traditional continuous grazing management system.

Procedure

Replicated continuous and SDG systems were developed by dividing a 160-acre smooth bromegrass pasture into four 40-acre cells. Two of these cells were further subdivided into eight 5-acre paddocks, each with electric fencing. The SDG cells were arranged in a radial design with a central work and watering area. All cells were mowed in early spring, prior to initiation of active growth of the grass, and fertilized in April with 60 lb nitrogen/acre each year. Water and a mineral supplement were available to the cattle at all times. Angus, Hereford, Charolais, and Angus x Hereford heifer calves born in September-October of the previous year were used in the study. Breeds were allocated equally between grazing systems and cells, and mean initial weights were equalized among cells (488 lb in 1982; 508 lb in 1983).

In 1982, the continuous and SDG treatments were stocked with 47 animals/40-acre cell. Heifers assigned to the SDG system were rotated on a predetermined schedule averaging 2.5 days of grazing per rotational paddock (range 2-4 days). Rotational order through the paddocks remained constant, with 18.5 days of rest (range 17-19 days) after each grazing bout. In 1982, grazing was initiated May 12 and terminated August 20 after 5 complete cycles through the rotational paddocks. During the second year of the study, the continuously grazed cells were again stocked with 47 animals/40-acre cell; however, the SDG system was increased to 62 heifers/40-acre cell. Grazing was initiated May 11, 1983, and terminated August 19, 1983. The grazing interval per paddock and number of cycles was the same as the previous year. Cattle were weighed after each rotational cycle was completed.

The available forage in each cell was sampled on the initiation date of the experiment each year and after completing each rotational cycle. Standing forage was clipped with hand shears from 42 quadrats (1 ft^2) in each continuously grazed cell, and 6 quadrats were clipped in each of the eight paddocks from the rotationally grazed cells. Total available forage, crude protein, and *in vitro* digestibility were determined from these clipping samples.

Results

Animal Response. Average daily gain (ADG) of heifers in 1982 is shown in Figure 1. Cattle grazing the continuous and SDG systems did not differ significantly in season-long ADG (1.06 *vs* 1.03 lb/day), but there was a decline ($P<.05$) in ADG as the grazing season progressed. When the SDG system was stocked more heavily in 1983 (131 pct of the continuous system), results (Fig. 2) were similar to the previous year. Animal gain averaged 1.23 and 1.14 lb/day over the entire grazing season for the continuous and SDG systems, respectively ($P>.05$). While productivity remained the same per animal between grazing systems, total productivity per acre increased 24.2 percent on the SDG system (147.4 *vs* 183.1 lb of gain/acre, $P=.05$) due to the increased stocking rate.

Forage Response. In 1982, available forage did not differ significantly between grazing systems, although there appeared to be about 36 percent more forage present under the SDG system on June 21, and available forage tended to remain greater throughout the rest of the summer (Fig. 3). During 1983, when the SDG system was stocked more heavily than the continuous system, available forage (Fig. 4) was the same for both systems except on the August 1 sampling date, when the continuous system had a greater ($P<.05$) amount of forage (1.22 *vs* .61 tons/acre). Forage quality in both 1982 and 1983 did not differ significantly for either *in vitro* digestibility or crude protein content between the grazing systems. As expected, forage quality declined ($P<.05$) dramatically as the season progressed (Table 1).

The study suggests that, when continuous and SDG systems are stocked equally, the pasture responds with increased forage production under the SDG management system. When the stocking rate was increased for the SDG system to utilize this extra forage, the total animal productivity per acre was increased. Individual animal performance was not improved by the SDG system at either stocking rate, presumably because forage quality was not improved by the SDG system as is usually assumed.

Table 1.—*In vitro* digestibility (IVD) and crude protein (CP) content of forage sampled after each rotational cycle. The values are averaged across both continuous and SDG system samples

	IVD (pct)		CP (pct)	
Sample	1982	1983	1982	1983
Initial	65.6[b]	73.6[b]	21.2[b]	17.1[b]
Cycle 1	66.2[b]	77.9[c]	13.1[c]	11.1[c]
Cycle 2	57.7[c]	66.4[d]	8.8[d]	7.1[d]
Cycle 3	50.9[d]	58.7[e]	7.4[e]	6.2[e]
Cycle 4	44.7[e]	53.8[f]	6.5[f]	4.0[f]
Cycle 5	34.9[f]	48.9[g]	5.5[g]	3.6[g]
SE[a]	.8	.8	.3	.1

[a]SE (standard error of the mean).
[bcdefg]Means in the same column not sharing a common superscript differ ($P<.05$).

[1]Jung is a research animal scientist, Production Systems Unit, MARC; Rice is a professor of animal science, University of Arizona; and Koong is the associate director, College of Agriculture, University of Nevada (formerly the research leader, Production Systems Unit, MARC).

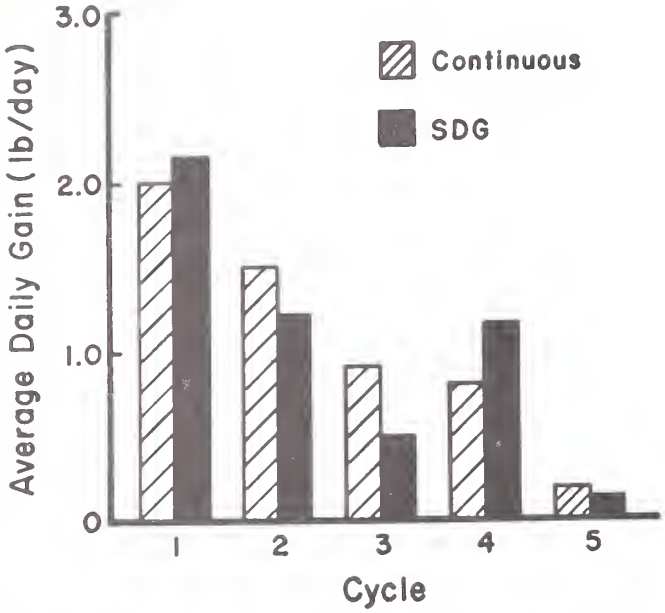

Figure 1—Average daily gain of heifers on smooth bromegrass pasture for continuous and short-duration grazing (SDG) systems through five rotational cycles in 1982. Grazing systems did not differ (P>.05) in gain.

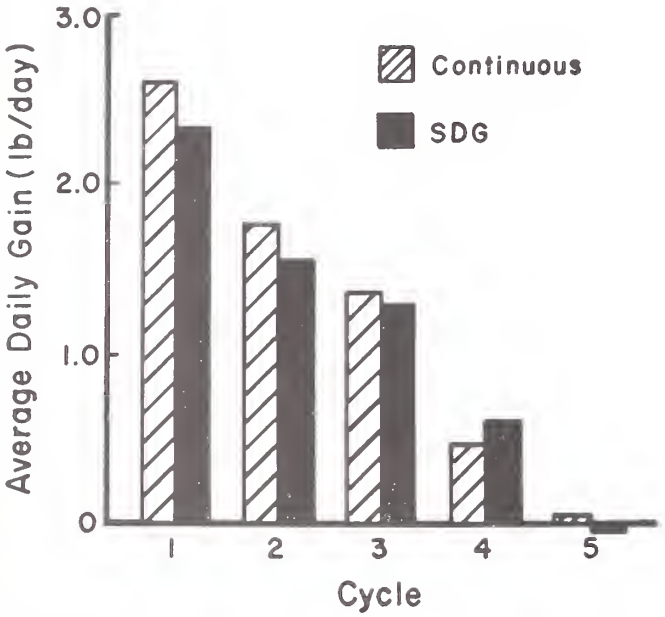

Figure 2—Average daily gain of heifers on smooth bromegrass pasture for continous and short-duration grazing (SDG) systems through five rotational cycles in 1983. Grazing systems did not differ (P>.05) in gain.

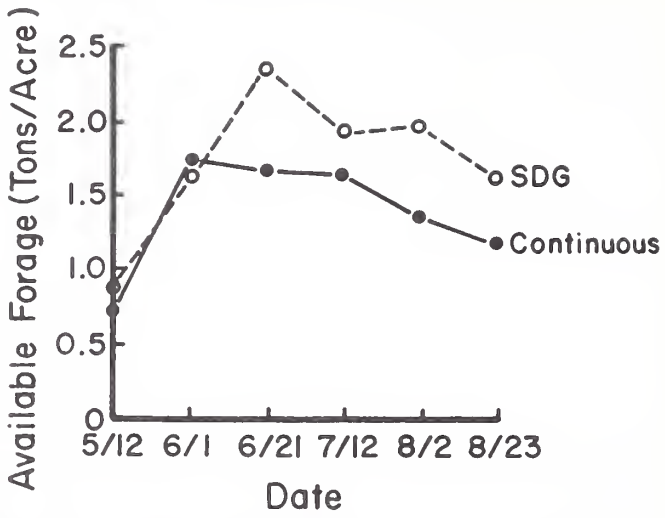

Figure 3—Available standing forage in the continuous and short-duration grazing (SDG) systems during 1982. Grazing systems did not differ (P>.05) in available forage.

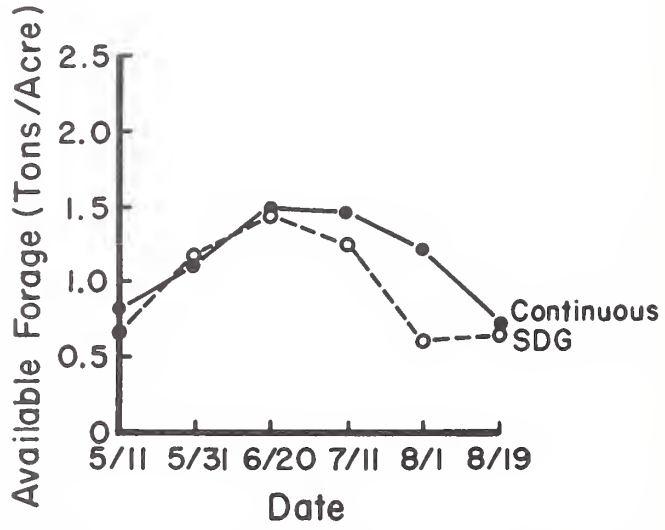

Figure 4—Available standing forage in the continuous and short-duration grazing (SDG) systems during 1983. Grazing systems were different (P<.05) in available forage on August 1.

Energy Requirements for Maintenance of Beef Cattle Differing in Genetic Potential for Mature Size and Milk Production

Thomas G. Jenkins and Calvin L. Ferrell[1]

Introduction

Relative differences in expected performance for breed crosses of cattle are provided elsewhere in this report; see "Characterization of Breeds Representing Diverse Biological Types." This information may be utilized by beef cattle producers to identify breed types for possible use in their beef cattle enterprises. In conjunction with information descriptive of production characteristics, variation in energy requirements among the breed types needs to be considered. Using general relationships between production potential and energy requirements, producers may identify the beef cattle breeds that would perform optimally in their respective production environments.

Energy (either harvested by the animal or provided via supplementation) is used by animals to sustain life of the individual (maintenance) and for product formation (growth, gestation, and lactation). The energy available for metabolism by animals is referred to as metabolizable energy (ME). The information presented within this report demonstrates variation among breed crosses in energy requirements for animal production and documents variation in energy requirements for maintenance during specified periods of production.

Procedure

A series of studies has been initiated to estimate energy requirements of cattle breeds or breed crosses at specified points in the production cycle. To date, energy requirements have been estimated for straightbred Hereford and Simmental bulls and heifers during the postweaning period; mature Angus, Charolais, Hereford, and Simmental cows during lactation; and mature Angus, Hereford, and Simmental cows that were nonpregnant and non-lactating. In addition, four breed crosses from Cycle I and six breed crosses from Cycle II of the Germ Plasm Evaluation (GPE) program have been evaluated. Breed crosses from the GPE project, for which maintenance energy requirements have been estimated are: Hereford x Angus and Angus x Hereford (AH-X), Charolais x Angus or Hereford (C-X), Jersey x Angus or Hereford (J-X), Simmental x Angus or Hereford (S-X), Red Poll x Angus or Hereford (RP-X), Brown Swiss x Angus or Hereford (BS-X), Gelbvieh x Angus or Hereford (G-X), Maine Anjou x Angus or Hereford (MA-X), and Chianina x Angus or Hereford (CH-X).

Feed intake for individual animals or replicated pens within breed was recorded biweekly for all cattle. Within a specific study, the cattle were fed to maintain body weight or were assigned to a restricted or *ad libitum* feed intake level. Body composition was estimated at the initiation and termination of the trials involving AH-X, C-X, J-X, S-X, and the Simmental and Hereford bulls and heifers via dilution techniques. Energy requirements for maintenance were predicted by regressing change in body energy or weight on metabolizable energy intake within each breed or breed cross.

Results

Information in Figure 1 depicts predicted annual energy requirements (Mcal ME) for mature cows representing four breed crosses produced in Cycle I of the GPE project that varied in genetic potential for mature size and milk production potential. The AH-X, C-X, J-X, and S-X have been previously characterized as exhibiting moderate-moderate, large-moderate, moderate-high and large-high genetic potential for mature size and milk production, respectively. The reported values are expressed relative to the AH-X for three physiological states (lactation, gestation, and maintenance) in mature cows. Relative to the AH-X, the S-X, J-X, and C-X required 28 percent, 6 percent, and 9 percent more energy for an annual production cycle. For the AH-X, approximately 19 percent of the ME was expended for lactation and 8 percent for gestation. The predicted energy expenditure of the C-X, J-X, and S-X breed crosses for gestation was similar. Differences among the breed crosses for ME expenditure for lactation reflect differences in total milk yield among the cows. For all breed crosses, the largest proportion of ME was spent for maintenance. Additionally, the greatest variation among the breed crosses for ME requirements was for maintenance. Two facts suggested by this information are: 1) differences exist in annual energy requirements among breed crosses that differ in genetic potential for mature size and lactation, and 2) the largest proportion of ME expenditure was associated with maintenance.

Estimates of maintenance requirements from several studies involving breeds and breed crosses varying in physiological states are reported in Table 1. Maintenance requirements are expressed as kilocalories of ME per unit metabolic size (weight in kilograms raised to the .75 power). The information is reported by trial within physiological state.

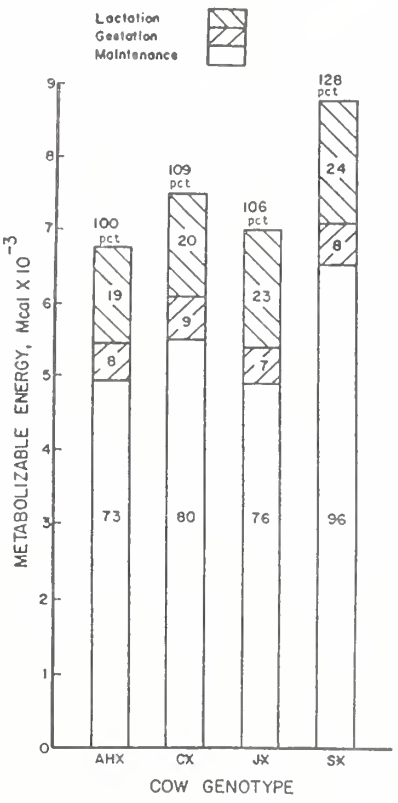

Figure 1—Estimated annual production cycle metabolizable energy requirements for Angus x Hereford-Hereford x Angus (AH-X), Charolais x Angus/Hereford (C-X), Jersey x Angus/Hereford (J-X) and Simmental x Angus/Hereford (S-X).

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During the finishing period, two breeds that would be expected to differ in postweaning growth rate were evaluated. The energy requirement for maintenance of the Simmental was greater than for the Hereford (126 *vs* 106 Kcal ME/wt^{75}/day). Relative to the average of the two breeds, Simmental required approximately 8 percent more energy per unit of metabolic size and Hereford, approximately 9 percent less.

Among non-lactating, non-pregnant F_1 cows from Cycle I of the GPE project, the S-X and J-X required a greater amount of ME per unit metabolic size than did the AH-X and C-X cows. Although the mature size of the C-X was greater than the AH-X, the energy requirements relative to metabolic body size were similar. These results suggest that genetic potential for lactation has a greater effect on maintenance energy requirements than size *per se*.

Among lactating Cycle II F_1 cows, the CH-X cows required the most ME per unit metabolic size and the MA-X required the least. Relative to the average of the six breed crosses involved in the study, the RP-X, G-X, and BS-X were similar to the average with the AH-X requiring approximately 4 percent less ME for maintenance.

Comparing straightbred cattle during non-lactating and lactating periods, the relative differences among the breeds remained approximately the same. The Simmental required more energy for maintenance than the Angus and Hereford during both the non-lactating and lactating physiological states. However, the ME requirements associated with metabolic body size were increased for Angus, Hereford, and Simmental during lactation relative to the non-lactating period. The ME requirements of the Charolais were similar to those of Simmental during lactation.

Efficient beef production requires the effective utilization of the resources that are available. Information is available documenting differences among breeds or breed crosses for output characteristics such as reproductive performance, growth, and lactation. There is increasing evidence that variation also exists among breeds for energy requirements during a production cycle. Metabolizable energy expenditure may be partitioned into the two broad classifications of maintenance and production (i.e., tissue accretion, lactation, etc.). The proportion of energy consumed that is expended upon the maintenance component exceeds the proportion utilized for production function. Variation among breeds or breed crosses in energy expenditure for maintenance has been documented.

Table 1.—Estimates of metabolizable energy required for maintenance of various breeds or breed crosses

Breed or breed cross	Physiological state	Age	Biological type classification for potential performance[a]: Growth rate and mature size	Biological type classification for potential performance[a]: Milk production	Maintenance (kcal/kg.^{75}/d)	Ratio[b] (pct)
	Finishing					
Hereford	Growing	9-15 mo	Moderate	Low	106	91
Simmental	Growing	9-15 mo	High	High	126	108
	Non-lactating					
Angus-Hereford[c]	Non-pregnant	9-10 yr	Moderate	Moderate	130	92
Charolais-X	Non-pregnant	9-10 yr	High	Low	129	91
Jersey-X	Non-pregnant	9-10 yr	Low	High	145	103
Simmental-X	Non-pregnant	9-10 yr	High	High	160	113
Angus	Non-pregnant	5-6 yr	Moderate	Moderate	118	95
Hereford	Non-pregnant	5-6 yr	Moderate	Low	120	97
Simmental	Non-pregnant	5-6 yr	High	High	134	108
	Lactating					
Angus	Non-pregnant	5-6 yr	Moderate	Moderate	149	96
Hereford	Non-pregnant	5-6 yr	Moderate	Low	141	91
Simmental	Non-pregnant	5-6 yr	High	High	166	107
Charolais	Non-pregnant	5-6 yr	High	Low	165	106
Angus-Hereford[c]	Pregnant	8-9 yr	Moderate	Moderate	151	96
Red Poll-X	Pregnant	8-9 yr	Moderate	High	157	100
Brown Swiss-X	Pregnant	8-9 yr	High	High	156	99
Gelbvieh-X	Pregnant	8-9 yr	High	High	158	100
Maine Anjou-X	Pregnant	8-9 yr	High	High	146	93
Chianina-X	Pregnant	8-9 yr	High	Low	174	111

[a]See "Characterization of Breeds Representing Diverse Biological Types: Reproduction and Maternal Performance of F_1 Cows" in this publication.
[b]Ration within study
[c]Crossbred cows produced by using Angus, Hereford, Charolais, Jersey, Simmental, Red Poll, Brown Swiss, Gelbvieh, Maine Anjou, or Chianina purebreds mated to Angus or Hereford cows.

Feed Requirements for Maintenance and Lactation of F_1 Cows Representing Diverse Biological Types

Larry V. Cundiff, Calvin L. Ferrell, and Thomas G. Jenkins[1]

Introduction

There are significant differences in weaning weight per cow exposed to breeding among F_1 cow breed groups. (See "Characterization of Breeds Representing Diverse Biological Types: Reproduction and Maternal Performance of F_1 Cows" elsewhere in this report.) These differences are associated with variation among breeds in reproduction, milk production, and growth rate of progeny. Also, there are significant differences among F_1 cows in mature weight. Heavier mature weight is associated with more rapid growth rate of progeny, and heavier weights increase output per cow from the production system when cows are sold. However, it also increases the nutrient requirements per cow for maintenance. Thus, it is important to quantify production inputs as well as outputs in order to characterize genetic variation in efficiency of production. The present study was conducted to estimate feed requirements for maintenance and lactation and to estimate biological efficiency (output/input) differences among F_1 cows representing diverse biological types.

Procedure

The cows used in this experiment were produced in 1973 and 1974 in Cycle II of the Germ Plasm Evaluation Program. The breed groups sampled included Hereford x Angus and Angus x Hereford (HA-X), Red Poll x Hereford and Red Poll x Angus (R-X), Brown Swiss x Hereford and Brown Swiss x Angus (B-X), Gelbvieh x Hereford and Gelbvieh x Angus (G-X), Maine Anjou x Hereford and Maine Anjou x Angus (M-X), and Chianina x Hereford and Chianina x Angus (Ci-X) F_1 crosses. The cows were raising Simmental-sired progeny, born in March and April of 1981 and 1982 when they ranged from 7 to 9 years of age. Cows and their progeny were moved from pastures to the feedlot at about 37 days after calving. Cows of each of the six different breed groups were assigned to replicated pens (2 pens/breed group/yr) of 12 cow-calf pairs per pen (breed of dam of cow, A and H, was balanced within each pen). The cows were fed to maintain their initial weight for a 138-day period commencing at about 45 days after calving in 1981 and 1982, respectively. Cow weights were recorded biweekly. If average weight per cow in a pen was decreased to a point below the initial weight (45 days post-calving), feed was increased for the pen. If the pen average weight increased to a point above the actual starting weight, feed was decreased for the pen in the subsequent 2-week period. This procedure was followed for 10 biweekly periods in each year. The average biweekly daily metabolizable energy (ME) consumption for each pen of cows was adjusted statistically to zero biweekly weight change using regression procedures (based on linear regression of mean daily weight change on mean daily ME consumption for 10 biweekly periods in each pen). The cow diet included corn silage (60 pct), alfalfa haylage (38 pct), and a supplement (2 pct) which included soybean meal, dicalcium phosphate, vitamin A, and trace minerals. Creep feed consumed by the progeny was also recorded. The creep feed was a pelleted diet (45 pct alfalfa hay, 45 pct corn, and 10 pct supplement including soybean meal, salt, trace minerals, vitamins A, D, E, and Duraband) in 1981 and whole oats in 1982.

Estimates of 12-h milk production were taken at an average of 24, 76, and 132 days after initiation of the experiment. Cows and calves were separated for 12 h after which calves were weighed, penned with their dams, allowed to nurse, and reweighed. The change in calf weight was used to estimate milk production. Fat thickness of the cows was measured by probing with a small gauge needle at the initiation and end of the experiment.

Results

Results for this experiment are summarized in Table 1. The averages over all breed groups are shown for weight gain and energy consumption of progeny; for milk production, initial weight, fat thickness, and energy consumption of the dams; and for the ratio of progeny gain per unit energy consumed by the cows and their progeny. Results for each trait are presented as ratio percentages to the overall mean according to breed-group of dam (e.g., a ratio of 97 for weight gain of progeny out of Hereford x Angus dams indicates that they gained 3 pct below the overall average of 346 lb, while a ratio of 103 for progeny of Brown Swiss dams indicates they gained 3 pct above average.)

Differences in gain and ME consumption of progeny raised by the six breed groups of cows were not significant. Perhaps this is not too surprising. The progeny groups differed for direct breed effects only by a one-fourth contribution from their maternal grandsire (i.e., H or A, R, B, G, M, Ci) and were 1/2 Simmental and 1/4 Hereford or 1/4 Angus. There was a tendency for calves out of higher-milking dams (B-X, G-X, M-X) to consume less creep feed than those out of dams producing relatively lower levels of milk (HA-X and R-X). An exception to this relationship was observed in Chianinas, in which progeny creep feed consumption and milk production of the dams were both relatively low.

Significant differences were found among F_1 cow breed groups for average milk production, initial weight, fat thickness (average of estimates measured at beginning and end of experiment) and energy consumption required to maintain weight during the 138.5-day period. The HA-X cows required significantly less feed than B-X, G-X, M-X, and Ci-X cows, and R-X cows required less than G-X, M-X, and Ci-X cows. The ratio of calf gain to energy consumed by the cow and calf was used as an estimator of efficiency. The HA-X, R-X, and M-X breed groups were significantly more efficient than the higher-milking B-X and G-X breed groups. However, efficiency of the Ci-X was low even though they had relatively low milk production. In general, increases in output of cows associated with higher genetic potential for size and milk production were offset, or more than offset, by increases in feed requirements of the cows for maintenance and lactation. Cows producing the most milk (B-X, G-X) or of largest mature weight (Ci-X, M-X) required the most feed. Progeny of cows with highest output potential for milk tended to consume less creep feed than progeny of cows with lower output potential for milk, but only 16.4 percent of the total energy was consumed by calves compared to 83.6 percent consumed by dams. Thus, differences in output/input favored the cows with lower input requirements (HA-X and R-X).

The cows with smaller mature size (HA-X and R-X) may have benefited more from "complementarity" than cows with larger mature size (B-X, G-X, M-X, and Ci-X) in this experiment, since all calves were the progeny of Simmental sires. Complementarity is exploited when crossbred cows of small to medium size and optimum milk production (maternal breeds) are mated to sires of a different breed noted for rapid growth rate and carcass leanness. Since Simmental cattle are about the same size as Brown Swiss, Gelbvieh, Maine Anjou, and Chia-

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nina but larger than Herefords, Angus, and Red Poll cattle, output/input of HA-X and R-X cows was probably favored relative to that of B-X, G-X, M-X, and Ci-X cows in this experiment.

Table 1.—Output/input differences among F_1 cows of diverse biological types

Item	Overall mean	Breed group[a]					
		HA-X	R-X	B-X	G-X	M-X	Ci-X
Progeny (138.5 days)							
Weight gain, lb	346	97	99	103	100	103	98
Energy consumed, Mcal ME	744	106	102	99	96	98	99
Dams (138.5 days)							
Milk production, lb/d	8.8	85	101	118	111	104	82
Cow weight, lb	1,138	98	91	97	100	107	107
Fat probe, in	.25	124	101	91	93	90	101
Energy consumed, Mcal ME	3,787	91	96	105	105	100	104
Efficiency (138.5 days)							
Progeny gain, lb/Mcal ME intake by cow and calf	.077	103	103	99	97	103	95

[a]Ratio percentages computed relative to overall mean where HA-X = Hereford or Angus, R-X = Red Poll, B-X = Brown Swiss, G-X = Gelbvieh, M-X = Maine Anjou, and Ci-X = Chianina sired F_1 crosses out of Hereford and Angus dams.

Effects of Managing Heifers to Calve First at Two *vs* Three Years of Age on Longevity and Lifetime Production of Beef Cows

Rafael Nunez-Dominquez, Larry V. Cundiff, Gordon E. Dickerson, Keith E. Gregory, and Robert M. Koch[1]

Introduction

Resources used by cow herds for beef production vary greatly. To optimize reproduction and other production characteristics in the cow herd, breeding and management should be matched with the feed resources available for production. One management decision is whether to develop replacement females to calve first as 2-year-olds or as 3-year-olds. When feed resources are limited or expensive relative to other costs and value of output, it may be economical to delay the first calving until 3 years of age. When feed resources are adequate to support rapid growth and development of heifers and thus to reduce age at puberty to 14 months of age or less, then calving at 2 years of age may be optimum. Another management decision is whether or not cows should be culled the first time they are open, or held over for another opportunity to breed (in lieu of keeping an additional replacement heifer). This study was conducted to evaluate effects of 2-year-old *vs* 3-year-old first calf management on longevity and lifetime production of cows and on current economics of beef production.

Procedure

Data on average annual production, cow survival, and cumulative production through 12 years of age were studied on 328 cows produced at the Fort Robinson Beef Cattle Research Station, Crawford, Nebraska, from 1960 through 1963. The cows were F_1 reciprocal crosses and straightbreds among the Hereford, Angus, and Shorthorn breeds. The cows were transferred from Fort Robinson to MARC in 1972, where the experiment was completed in 1975.

The heifers produced in 1960 and 1961 were grown under a management program appropriate for producing their first calves as 3-year-olds. Those produced in 1962 and 1963 were grown under a management program appropriate for producing their calves as 2-year-olds. Heifers from the first two calf crops received 1.0 lb of 40 percent protein supplement per head/day on native range during their first winter, whereas the heifers from the last two calf crops received about 4.5 lb of concentrate feed per head/day in addition to a liberal feeding of hay and access to limited winter range. These management programs were designed to produce gains of about 0.5 lb and 1.0 lb per day, respectively, for the two groups during the 196-day wintering period. Except for level of feeding in their first wintering period and age at which they were first assigned to breeding pastures, all females were managed as one group after they entered the breeding herd.

The cows were run on native range at Fort Robinson or on improved cool-season brome pastures at MARC. During winter months, hay was fed *ad libitum*. Protein requirements were met by either feeding alfalfa hay or a 40 percent protein supplement. The cows were exposed to natural service breeding for about 75 days, commencing in late May or early June each year. Cows were diagnosed for pregnancy in the fall each year.

Results

Average annual production. Results in Figure 1 show that calf crop percentage weaned was low for heifers raising their first calves as 2-year-olds, but, at ages 3 through 12 years, their calf crop percentage was comparable to that of females managed to calve first as 3-year-olds. Results in Table 1 show that, over all ages, pregnancy rates and calf crop percentage at birth, at 72 h, and at weaning, were about the same for females bred first at 1 year of age to calve as 2-year-olds (M1) as for females bred first at 2 years of age to calve as 3-year-olds (M2).

Average 200-day weaning weight per calf and per cow exposed (cow gets credit for weaning wt of a live calf weaned or a credit of zero if no calf weaned) are shown in Figure 2. As expected, weaning weights increased as cows advanced from 2 or 3 years of age to mature ages (5 to 9 yr) and then decreased as cows became older. On the average, 200-day weaning weight per calf and per cow exposed were higher for M2 cows than for M1 cows (Table 1). This difference was due in part to the low weight of calves out of 2-year-old first calf females. If only the 10 calvings from 3 through 12 years of age are considered in both management regimes, production by M1 cows, compared to M2 cows, was lower for weaning weight per calf (434 lb *vs* 449 lb) but was nearly the same for weaning weight per cow exposed (345 lb *vs* 349 lb).

Cow survival. Survival of cows under 2-year-old (M1) and 3-year-old (M2) first calving management programs is shown in Figure 3 under the actual (A) and imposed (I) culling policies. A different trend for survival of M1 and M2 females was observed depending on culling procedure. The interaction favored AM1 over IM1 much more than AM2 over IM2 and suggests that the actual practice (AM1), culling open females as yearlings but allowing them to stay in the herd if open their second breeding season while raising their first calf, increased their probability of surviving in the herd greatly relative to that for the imposed practice of culling females that failed to rebreed while raising their first calves as 2-year-olds (IM1). Also, AM1 females tended to have higher survival rates than AM2 females after 3 years of age, suggesting that culling of females for infertility at a year of age may be more effective at improving fertility at older ages than culling for infertility the first time as 2-year-olds.

The data in Figure 3 show that, under the imposed culling policy, differences in number of breeding seasons, or opportunities to cull for failure to conceive, account for most of the differences between IM1 and IM2 at any given age. For example, after seven breeding seasons in both systems, survival is more nearly the same for IM1 (about 48.5 pct at 7 yr) and IM2 (about 50.5 pct at 8 yr) than at the same age. Differences between IM1 and IM2 are even smaller after 2, 3, 4, 5, 6, 8, or 9 breeding seasons, emphasizing the importance of infertility or conception failures on cow survival under the imposed culling policy.

Cumulative lifetime production. If breeding heifers at 1 year of age to calve first as 2-year-olds (M1) has no adverse consequences on subsequent reproduction and maternal performance, then the M1 system must yield greater lifetime performance than breeding heifers as 2-year-olds, because it will potentially produce an extra calf. Cumulative production of calf weight weaned through 12 years of age is shown in Figure 4 for females first mated as yearlings (M1) or as 2-year-olds (M2) under the A and I culling policies. Reproductive components of cumulative lifetime production are shown in Table 2. Under the actual culling policy to 12 years of age, AM1 experienced 1.2 more breeding seasons, 1.2 more pregnancies, gave birth to 1.1 more calves, weaned .9 more calves, and produced a total of 304 lb more 200-day calf weight than AM2 cows. Under the imposed culling policy, the differences were

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not nearly as favorable for the IM1 over IM2 because of the reduced survival (Figure 3) and longevity of IM1 cows compared to IM2 cows (longevity, 6.9 *vs* 7.8 yr, respectively). Under the imposed system, although females were exposed to breeding a year earlier, by 12 years they experienced only .4 more breeding opportunities, resulting in .3 more pregnancies, .3 more calves born, and .2 more calves weaned. Since these additional calves were raised at relatively young ages (see Fig. 2), cumulative lifetime production of cows up to 12 years of age was slightly less (53 lb, or 2.5 pct) for the IM1 cows than for IM2 cows. This result casts doubt on the advisability of culling females the first time they are open after calving at 2 years of age or older (IM1), provided their fertility was established by pregnancy as a yearling (AM1).

Economics. Income for alternative age at first calving management and culling policies are compared in Table 3, assuming that all cows are sold after weaning their last calves at 12 years of age. Gross income of M2 cows was $997 higher than that for M1 cows under the A culling policy. Under the I culling policy, gross income of M2 cows was $1,461 above that for M1 cows. However, replacements of M2 cows have to be maintained an extra year. When costs of growing replacements is considered (see footnote e, Table 3), adjusted income of M1 cows was $2,161 and $2,018 greater than for M2 cows under the A and I culling policies, respectively. Adjusted income under A and I culling policies was similar. Extra costs of growing more replacements under the I culling policy was compensated for by higher income from salvage value of cows. Current U.S. tax laws favor the I culling policy, since income from sale of cows is considered as a capital gain and taxed at a lower rate than income from sale of calves. These results indicate that managing heifers to calve first as 2-year-olds is more profitable than managing heifers to calve first as 3-year-olds under either culling policy, assuming current differences in feed costs and other resources required to develop heifers to breed first at 1 *vs* 2 years of age.

Table 1.—Average annual lifetime production of cows managed to calve first as 2-year-olds and as 3-year-olds

Item	2-year-old first calving management	3-year-old first calving management
Pregnancy rates, pct[a]	88.1	85.1
Calf crop born, pct[a]	84.1	82.1
Calf survival to 72 h, pct[a]	81.0	80.2
Calf crop weaned, pct[a]	77.7	77.3
Birth weight per calf born, lb	77.2	76.7
200-day wt per calf weaned, lb	429	449
200-day wt per cow exposed, lb	336	349.5

[a]Per cow exposed to breeding

Table 2.—Cumulative lifetime production up to 12 years of age per female initially assigned to breeding pastures to calve first as 2-year-olds and as 3-year-olds under two culling policies[a]

	Actual culling		Imposed culling	
Item	2-yr-old first calving (AM1)	3-yr-old first calving (AM2)	2-yr-old first calving (IM1)	3-yr-old first calving (IM2)
Number of breeding seasons	8.5	7.3	6.3	5.9
Number of pregnancies	7.4	6.2	5.5	5.2
Number of calves born	6.8	5.7	5.2	4.9
Number of live calves at 72 h	6.6	5.6	5.0	4.8
Number of calves weaned	6.3	5.4	4.8	4.6
Total 200-day weight weaned, lb	2,736.2	2,431.4	2,057.0	2,110.4

[a]*Actual culling policy.* Heifers and cows 10 years old or older diagnosed as not pregnant were culled the first time they were open. After the first breeding season throught 9 years of age, cows failing to conceive in two successive breeding seasons were culled. Cows were also culled for severe unsoundness.

Imposed culling policy. Females were culled the first time they were open regardless of age and for severe unsoundness.

Table 3.—Estimated annual output in herds of 100 cows managed to calve first as 2-year-olds or 3-year-olds under actual and imposed culling policies

	Actual culling		Imposed culling	
Item	2-yr-old first calving (AM1)	3-yr-old first calving (AM2)	2-yr-old first calving (IM1)	3-yr-old first calving (IM2)
No. of replacement heifers[a]	12.36	14.38	16.53	17.47
Gross weaning weight output, lb	33,664	34,932	33,946	36,854
Net weaning weight output[b], lb	29,503	29,909	28,334	30,416
Income from calves[c], $	15,636	15,868	15,016	16,120
Salvage value of cows[d], $	4,111	4,876	5,785	6,142
Gross income, $	19,747	20,744	20,801	22,262
Cost of growing replacement heifers[e], $	3,067	6,225	4,101	7,580
Adjusted income[f], $	16,680	14,519	16,700	14,682

[a]The age distribution of cows was assumed to be at equilibrium with all cows removed at 12 years of age.

[b]Gross output minus weight of proportion of replacement heifers required.

[c]Net output of weight at weaning times value (53 cents per lb, averaged 1972 to 1982, USDA Agricultural Statistics, 1983).

[d]Assuming mean cow weight found in study of 1,124 lb times value (33.69 cents per lb, averaged 1972 to 1982, USDA Agricultural Statistics, 1983).

[e]From budgets estimated by Nebraska Cooperative Extension Service, 1984, a cost from weaning to 14 months of $248.10 per heifer for 2-year-old first calving management and a cost from weaning to 26 months of $433.90 per heifer for 3-year-old first calving management.

[f]Value of output free of differences in replacement costs.

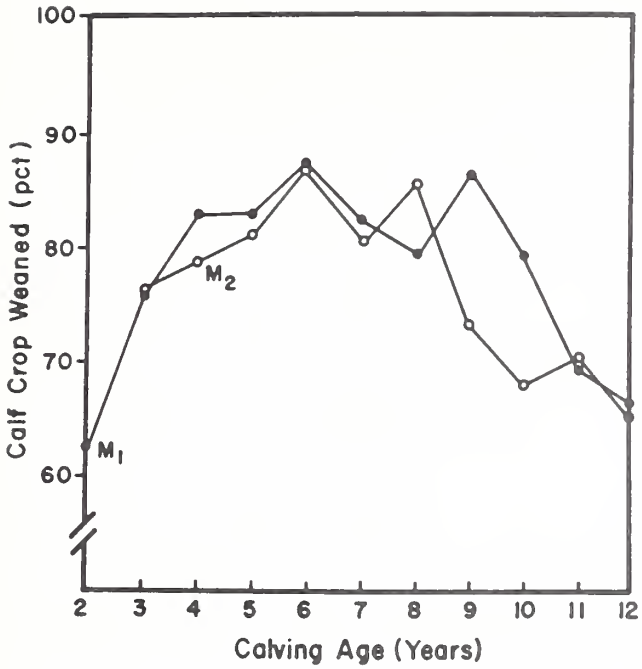

Figure 1—Calf crop weaned per cow exposed to breeding by age for cows first mated as yearlings (M1) or 2-year-olds (M2) under the actual culling policy.

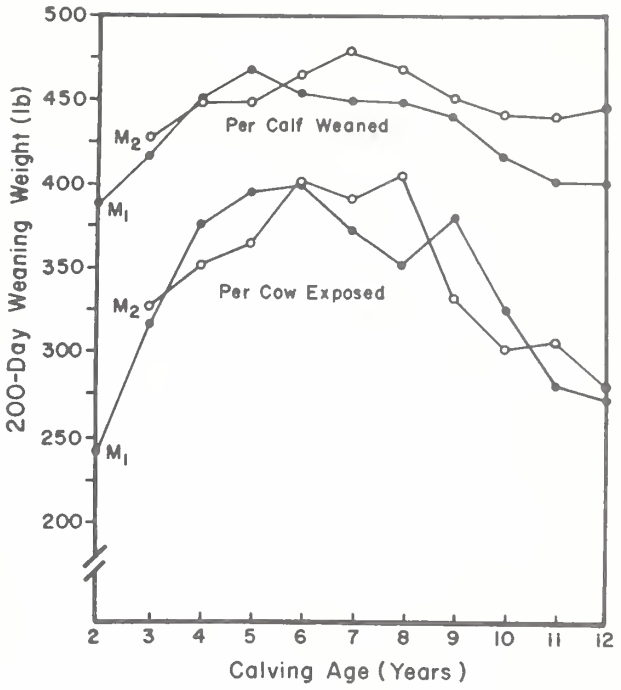

Figure 2—Weaning weight per calf weaned and weaning weight per cow exposed to breeding by age for cows first mated as yearlings (M1) or 2-year-olds (M2) under the actual culling policy.

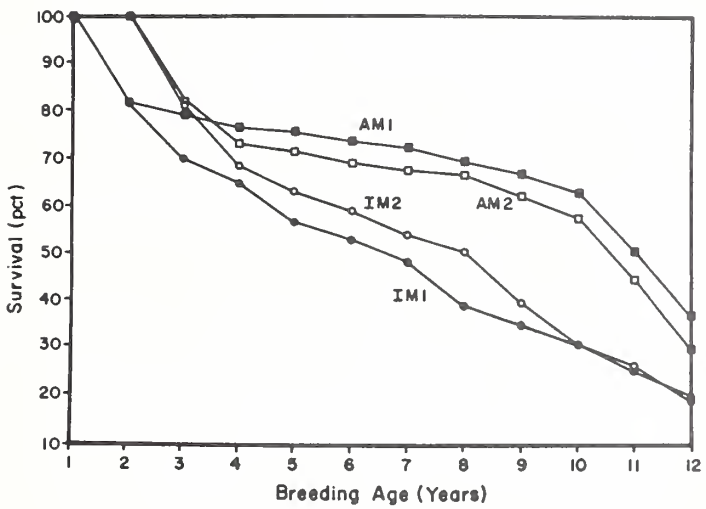

Figure 3—Cumulative survival of cows first mated as yearlings (M1) or as 2-year-olds (M2) under the actual (A) and imposed (I) culling policies.

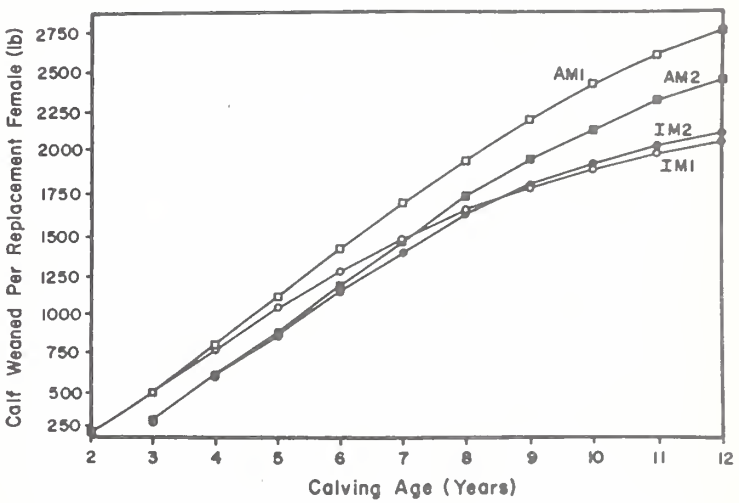

Figure 4—Cumulative productivity of all cows first exposed to breeding either as yearlings (M1) or as 2-year-olds (M2) under the actual (A) and imposed (I) culling policies.

Effects of Late Castration and Zeranol on Growth Rate, Feed Efficiency, and Carcass and Meat Traits of Bovine Males

Keith E. Gregory, J. Joe Ford, Steven C. Seideman, and W. Gordon Hays[1]

Introduction

It is generally recognized that intact bovine males gain weight faster and require less feed per unit of gain than castrate bovine males. Further, carcasses from intact bovine males have a higher percentage of retail or edible product, but meat from intact males is generally evaluated slightly lower on palatability characteristics, particularly tenderness, than carcasses from castrate bovine males. It has been suggested that much of the advantage of intact *vs* castrate males for rate of gain, efficiency of gain, and composition of gain may be expressed by an age of about 1 year and the disadvantages, including aggressive male behavior, that result in reduced rate and efficiency of gain, begin at about 1 year of age (at or immediately after puberty). Thus, there was need to determine the effects of castration at about 1 year on rate of gain, efficiency of gain, composition of gain, meat characteristics, and behavioral characteristics. Reports have shown that, when the anabolic agent zeranol [6-(6,10-dyhydroxyundecyl)-B-resorcyclic acid-d-lactone] is implanted in intact male calves at or before weaning, rate of gain is increased and rate of testicular growth is decreased. These experiments were conducted to determine the effects of castration and zeranol implants at 13 months of age on rate of gain, efficiency of gain, behavioral characteristics, and carcass and meat traits of bovine males.

Procedure

Two experiments were conducted. In experiment I, a total of 280 young bulls from five breed groups with an average age of 13 months were assigned to five experimental treatments as follows: (1) emasculator castration at day 0; (2) surgical castration at day 0; (3) intact; (4) intact, implanted in ear at days 0 and 70 with 36 mg of zeranol; and (5) intact, implanted in ear at day 0 with 72 mg of zeranol (Table 1). Average initial weight on experiment was 1,023 lb. Breed groups included in the experiment were either seven-eighths or purebreds of the Gelbvieh, Charolais, and Limousin breeds and two composite populations (MARC I and MARC II). MARC II population has one-fourth of their ancestry contributed by each of the Hereford, Angus, Gelbvieh, and Simmental breeds, and MARC I population averaged the following breed composition: one-fourth each of Charolais, Limousin, and Brown Swiss (dual-purpose type), and one-eighth each of Hereford and Angus.

The two types of castrates were fed together by breed group. Samples of MARC I, MARC II, and Limousin were fed separately for each treatment to provide three of the five replicates per treatment; 28 Gelbvieh and 32 MARC II that had been fed together since weaning were assigned to each of the five treatments as one replicate, and 30 Charolais and 28 MARC I that had been fed together since weaning were assigned to each of the five treatments as one replicate (Table 1). There were 20 pens in the experiment. Animals were assigned to treatment by breed group at random within initial weight strata. Animals in each pen had been fed together since weaning at about 200 days. Further detail of experimental design is provided in Table 1. Feeding period for experiment I was 141 days.

In experiment II, a total of 231 bulls representing seven breed groups (Table 2) were assigned to one of four treatments: (1) surgical castration at 13 months of age; (2) intact; (3) intact, implanted in scrotum with 36 mg of zeranol; or (4) intact, implanted in ear with 36 mg of zeranol (Table 2). Zeranol implants were inserted into the ear as described by the manufacturer or were placed into the septum of the scrotum, approximately one-third of the distance from the body to the epididymal end of the testis. From weaning until initiation of the experiment, bulls were penned by breed group. Thus, animals from seven different source pens were mixed when experiment II was initiated (Table 2). Mean age at initiation of the 103-day experimental period was 395 days. Animals were stratified by weight, within breed group, assigned randomly within strata to treatments, and were fed in pens of 28 to 30 with two pens/treatment. All breeds were represented within each pen (Table 2).

Diet fed since weaning and for the first 57 days in experiment I and the first 29 days in experiment II on a dry matter (DM) basis was 22 percent corn, 66 percent corn silage, and 12 percent protein-mineral-vitamin supplement composed primarily of soybean oil meal. The diet fed for the last 84 days of experiment I and the last 74 days of experiment II on a DM basis, was 70 percent corn, 25 percent corn silage, and 5 percent protein-mineral-vitamin supplement. Dietary energy density was 2.69 Mcal metabolizable energy (ME)/kg DM for the first 57 days of experiment I and the first 29 days of experiment II, and 3.04 Mcal ME/kg DM for the last 84 days of experiment I and the last 74 days of experiment II. Dietary

Table 1.—Number of animals by treatment and breed group - experiment I

	Treatment					
Breed group	Emasculator castration	Surgical castration	Intact	Intact 36-mg implant[a]	Intact 72-mg implant[b]	Total
MARC I[ce]	16	15	15	18	15	79
MARC II[de]	21	19	20	20	19	99
Gelbvieh[d]	5	6	5	6	6	28
Charolais[c]	5	6	7	6	6	30
Limousin[e]	9	9	8	9	9	44
Total	56	55	55	59	55	280

[a]Implanted at days 0 and 70 with 36 mg of zeranol.
[b]Implanted at day 0 with 72 mg of zeranol.
[c]Twenty-eight MARC I (1/8 Hereford, 1/8 Angus, 1/4 Charolais, 1/4 Brown Swiss, 1/4 Limousin) and 30 Charolais that had been fed together previously were assigned at random by breed group to each of the five treatments as one replicate.
[d]Twenty-eight Gelbvieh and 32 MARC II (1/4 Hereford, 1/4 Angus, 1/4 Gelbvieh, 1/4 Simmental) that had been fed together previously were assigned at random by breed group to each of the five treatments as one replicate.
[e]The three other replicates in each treatment were MARC I, MARC II, and Limousin.

Table 2.—Number of animals by treatment and breed group - experiment II[a]

	Treatment				
Breed group	Intact	Surgical castration[b]	Scrotal implant[c]	Ear implant[d]	Total
Red Poll	11	11	10	10	42
Hereford	9	9	10	10	38
Angus	12	9	10	10	41
Pinzgauer x Angus	11	11	11	10	43
Brown Swiss	9	9	9	8	35
Simmental	5	5	6	6	22
Gelbvieh	2	3	3	2	10
Total	59	57	59	56	231

[a]Two pens were used for each treatment.
[b]Castration at day 0; mean age of 395 days.
[c]Implanted in scrotum at day 0 with 36 mg of zeranol.
[d]Implanted in ear at day 0 with 36 mg of zeranol.

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crude protein was 12.88 percent for the first 57 days of experiment I and the first 29 days of experiment II, and 10.93 percent for the last 84 days of experiment I and the last 79 days of experiment II. Diets were fed *ad libitum* throughout the experiment. Feed bunk space was 90 ft in each pen, and each pen was 220 ft deep. Animals were weighed initially and on days 11, 29, 57, 85, 113, and 141 of experiment I and initially and on days 11, 29, 57, 85, and 103 of experiment II. Feed consumption was recorded by pen for each gain period.

Testicular weights were recorded at castration for surgical castrate males and at slaughter for all other males except the emasculator castrates. Scores for degree of development of secondary sex characteristics were recorded on days 0, 85, and 141 of experiment I and on days 0 and 85 of experiment II (8 = high degree of masculinity, 5 = medium degree of masculinity, 2 = small degree of masculinity). Different types of aggressive male behavior (fighting, riding, and pushing-shoving) were recorded for all treatment groups at different hours of the day throughout both experiments. Animals were hauled about 40 miles and slaughtered immediately after arrival at a commercial slaughter facility. Preslaughter stress associated with mixing animals from different pens was avoided. Carcass data were recorded approximately 24 h postslaughter. Cutability and retail product percentage and retail product weight were estimated by prediction equations.

Four treatment groups from experiment I were sampled (94 carcasses) to determine the effects of experimental treatment on meat traits (Table 3). Average liveweight at slaughter of the carcasses sampled was 1,385 lb at an average age of 17 months and a carcass weight of 884 lb.

Boneless 5th through 12th rib cuts were taken 24 h postslaughter from the right side of 94 carcasses representing the four treatment groups. Marbling scores were determined before ribs were removed. Ribs were vacuum packaged and frozen for about 4 months at −4°F, after which they were removed from storage and prepared for chemical analysis and sensory evaluation. Number of animals by treatment and breed group from which ribs were sampled is shown in Table 3.

Table 3.—Number of animals by treatment and breed group - meat traits

	Treatment				
Breed group	Castrate	Intact	Intact 36-mg implant[a]	Intact 72-mg implant[b]	Total
MARC II	8	17	13	12	50
Charolais	8	7	4	4	23
Limousin	4	9	4	4	21
Total	20	33	21	20	94

[a]Implanted in ear at days 0 and 70 with 36 mg zeranol.
[b]Implanted in ear at day 0 with 72 mg zeranol.

Ribs were cut into steaks 1 in thick starting at the 12th rib. The longissimus muscle was removed from the first steak from the 12th rib end and fat and moisture percentage of the longissimus muscle were determined by ether extract and by oven-drying. Longissimus muscle protein percentage was determined by difference. Steaks two and four were used for sensory panel evaluation. Steak three was used for shear force measurement with a Warner-Bratzler shear device.

Steaks were thawed 24 h at 37°F and then cooked on Farberware Open Hearth broilers to an internal temperature of 162°F as monitored by copper constantan thermocouples placed in the geometric center of each steak. A 10-member trained sensory panel evaluated 3/4 in cubes of each steak for juiciness (8 = extremely juicy, 1 = extremely dry), overall tenderness (8 = extremely tender, 1 = extremely tough), beef flavor intensity (8 = extremely intense, 1 = extremely bland), amount of panel detectable connective tissue (8 = none, 1 = abundant) and ease of fragmentation (8 = extremely easy, 1 = extremely difficult).

Table 4.—Least-squares means and standard errors for gains and weights - experiment I

Item	Initial weight, lb	ADG[a] 0-141 day, lb	Total gain 141 day, lb	Final weight, lb
Treatment				
Level of significance[b]	NS	**	**	**
Emasculator castrates	1,025 ± 15.6	2.0 ± .07[e]	282 ± 8.2[e]	1,308 ± 8.2[e]
Surgical castrates	1,021 ± 15.0	2.0 ± .04[e]	278 ± 7.7[e]	1,299 ± 7.8[e]
Intact	1,021 ± 15.2	2.6 ± .04[f]	388 ± 7.9[f]	1,409 ± 8.0[f]
Intact 36-mg implant[c]	1,023 ± 14.8	3.1 ± .04[g]	421 ± 7.5[g]	1,444 ± 7.7[fg]
Intact 72-mg implant[d]	1,028 ± 15.0	3.1 ± .04[g]	441 ± 7.7[g]	1,466 ± 7.8[g]

[a]ADG = average daily gain.
[b]NS = not significant.
[c]Implanted in ear at days 0 and 70 with 36 mg of zeranol.
[d]Implanted in ear at day 0 with 72 mg of zeranol.
[efg]Values having no superscript letter in common differ at P≤.05 level.
**P<.01.

Table 5.—Least-squares means for feed efficiency (141 days) - experiment I

Item	Mcal ME/ kg gain	Kg dry matter/ kg gain	Mcal ME/kg estimated retail product	Kg dry matter/ kg estimated retail product
Treatment				
Level of significance	**	**	*	*
Castrates	29.91 ± .52[c]	10.32 ± .18[c]	14.27 ± .34[c]	4.93 ± .12[c]
Intact	21.31 ± .52[d]	7.34 ± .18[d]	12.65 ± .34[d]	4.36 ± .12[d]
Intact 36-mg implant[a]	20.45 ± .52[d]	7.05 ± .18[d]	12.64 ± .34[d]	4.36 ± .12[d]
Intact 72-mg implant[b]	19.77 ± .52[d]	6.81 ± .18[d]	12.82 ± .34[d]	4.42 ± .12[d]

[a]Implanted in ear at days 0 and 70 with 36 mg zeranol.
[b]Implanted in ear at day 0 with 72 mg zeranol.
[cd]Values having no superscript letter in common differ at P≤.05 level.
*P<.05.
**P<.01.

Table 6.—Least-squares means and standard errors for secondary sex characteristics score and testicular weight - experiment I

Item	Secondary sex characteristics score[a]			Testicular weight	
	Initial	Day 85	Day 141	Initial, lb	Slaughter, lb
Treatment					
Level of significance[b]	NS	**	**		NS
Emasculator castrates	5.0 ± .12	3.8 ± .12[e]	2.7 ± .11[e]		
Surgical castrates	5.0 ± .11	3.7 ± .11[e]	2.6 ± .10[e]	1.1 ± .04	
Intact	5.1 ± .11	6.3 ± .11[f]	7.3 ± .10[f]		1.3 ± .04
Intact 36-mg implant[c]	4.8 ± .11	6.2 ± .11[f]	7.4 ± .10[f]		1.3 ± .04
Intact 72-mg implant[d]	5.1 ± .11	6.4 ± .11[f]	8.0 ± .10[g]		1.2 ± .04

[a]8 = high degree of masculinity, 5 = medium degree of masculinity, 2 = small degree of masculinity.
[b]NS = not significant.
[c]Implanted at days 0 and 70 with 36 mg of zeranol.
[d]Implanted at day 0 with 72 mg of zeranol.
[e][f][g]Values having no superscript letter in common differ at P≤.05 level.
**P<.01.

Shear force measurements were made after thawing and cooking steaks by the same procedures used for the sensory panel evaluations. Three .5 in^2 cores were taken from each cooled steak, parallel to fiber direction and sheared perpendicular to fiber direction in a Warner-Bratzler shear device.

Results

Experiment I. Method of castration did not affect rate of gain (Table 4). Intact males not implanted with zeranol gained 38.6 percent more (P<.01) during the 141-day period than castrate males. Intact males from the two zeranol implant treatment groups did not differ from each other in gain, but averaged 11.1 percent more (P<.01) during the 141-day period than males from the intact treatment group not implanted (Table 4). Castrate males required 40.4 percent more (P<.01) metabolizable energy (ME) and dry matter (DM)/unit of gain than intact males not implanted, but intact males implanted with zeranol did not require less (P>.05) ME or DM/unit of gain than intact males not implanted (Table 5). Males castrated at 13 months showed a progressive decrease in secondary sex characteristics during the 141-day feeding period, while males from the three intact treatments showed a progressive increase (Table 6). Zeranol did not have an effect on testicular weight (Table 6) or on aggressive male behavioral characteristics. Castrate males had greater (P<.01) fat thickness at 12th rib, higher (P<.01) marbling score, and lower (P<.01) cutability and retail product percentage than the males from the three intact treatments, which did not differ (P>.05) from each other in traits associated with carcass composition (Table 10). The effect of treatment on lean color score, though significant, was not of major importance; all treatments produced meat of acceptable color (Table 10). The longissimus muscle of castrate males had a finer texture (P<.01) than longissimus muscle from males from intact treatments, which did not differ (P>.05) from each other (Table 10).

Experiment II. Intact males gained 24 percent faster (P<.05) and consumed 22 percent less (P<.01) feed/unit of gain than males castrated at 13 months of age (Tables 7 and 8). Zeranol implants did not have a significant effect on average daily gain, feed efficiency, or carcass traits (Tables 7, 8, and 11). Late castration reduced (P<.01) carcass weight, estimated cutability (percentage), and estimated retail product (percentage). Dressing percentage and scores for marbling, final maturity, lean color, and lean texture were not affected significantly by late castration or zeranol treatment (Table 11). Secondary sex characteristic scores for males castrated at 13 months of age decreased during the experiment and on day 85 were lower (P<.01) than observed in intact males (Table 9).

Meat Traits. Samples of longissimus muscle from 94 males from experiment I representing four treatments [(1) castrated at 13 months; (2) intact; (3) intact, implanted with 36 mg zeranol at days 0 and 70; and (4) intact, implanted with 72 mg zeranol at day 0] were evaluated for a series of composition and palatability characteristics (Table 12). Longissimus muscle from castrate males generally had a higher score for marbling, a higher percentage of fat, a lower shear force value, and was evaluated more desirable by sensory panel scores for ten-

Table 7.—Least-squares means and standard errors for gains and weights - experiment II

Treatment	Initial weight, lb	ADG[a] 0 to 103 days, lb	Total gain 103 days, lb	Final weight, lb
Castrate	942 ± 11.9	2.2 ± .07[b]	216 ± 6.8[b]	1,160 ± 6.3[b]
Intact	953 ± 12.6	2.9 ± .07[c]	284 ± 7.5[c]	1,237 ± 6.7[c]
Scrotal implant	944 ± 11.7	2.6 ± .07[c]	280 ± 6.8[c]	1,222 ± 6.2[c]
Ear implant	948 ± 12.6	2.6 ± .07[c]	267 ± 7.3[c]	1,215 ± 6.8[c]

[a]ADG = average daily gain.
[bc]Means within columns with different superscripts differ (P<.05).

Table 8.—Least-squares means and standard errors for feed efficiency (103 days) - experiment II

Treatment	Mcal/kg gain	Kg dry matter/kg gain	Mcal/kg retail product	Kg dry matter/kg retail product
Castrate	25.7 ± .38[b]	8.77 ± .13[b]	11.8 ± .28	4.02 ± .10
Intact	20.0 ± .38[a]	6.81 ± .13[a]	10.4 ± .28	3.54 ± .10
Scrotal implant	20.9 ± .38[a]	7.01 ± .13[a]	11.1 ± .28	3.79 ± .10
Ear implant	21.2 ± .38[a]	7.22 ± .13[a]	10.6 ± .28	3.62 ± .10

[ab]Means within columns with different superscripts differ (P<.01).

Table 9.—Least-squares means and standard errors for testicular weight and initial and final live animal secondary sex characteristics score - experiment II

Treatment	Secondary sex characteristics score[a]		Testicular weight, lb
	Initial	Final	
Castrate	4.8 ± .1	3.9 ± .1[b]	
Intact	4.7 ± .1	5.8 ± .1[c]	1.2 ± .05
Scrotal implant	4.9 ± .1	6.0 ± .1[c]	1.1 ± .05
Ear implant	5.2 ± .1	6.2 ± .1[c]	1.1 ± .05

[a]Nine point scoring system; 8 = high degree of masculinity, 5 = medium degree of masculinity, 2 = small degree of masculinity.
[bc]Means within columns with different superscripts differ (P<.01).

Table 10.—Least-squares means and standard errors for carcass traits - experiment I

Traits	Level of signif-icance	Treatment				
		Emasculator castrates	Surgical castrates	Intact	Intact 36-mg implant[g]	Intact 72-mg implant[h]
Hot carcass weight, lb	**	803 ± 13.4[i]	809 ± 12.8[i]	904 ± 13.2[j]	919 ± 12.8[jk]	946 ± 12.8[k]
Dressing percentage	**	61.4 ± .33[i]	62.4 ± .32[i]	64.0 ± .32[j]	63.8 ± .31[j]	64.5 ± .32[j]
Adj. hot carcass weight[a], lb	**	807 ± 12.7[i]	807 ± 12.1[i]	902 ± 12.3[j]	924 ± 12.1[jk]	950 ± 12.3[k]
Adj. fat thickness[a], in	**	.30 ± .02[i]	.26 ± .02[i]	.17 ± .02[j]	.18 ± .02[j]	.21 ± .02[j]
Longissimus area, in[2]	**	14.8 ± .28[i]	15.2 ± .26[i]	17.7 ± .26[j]	16.9 ± .26[j]	16.9 ± .26[j]
Est. KPH fat[a], percent	**	1.9 ± .07[i]	2.0 ± .07[i]	1.6 ± .07[j]	1.6 ± .07[j]	1.6 ± .07[j]
Est. cutability[a], percent	**	63.5 ± .29[i]	64.4 ± .27[i]	67.1 ± .28[j]	66.7 ± .27[j]	66.3 ± .27[j]
Est. retail product[a], percent	**	77.8 ± .34[i]	78.9 ± .33[i]	82.2 ± .34[j]	81.7 ± .32[j]	81.2 ± .33[j]
Secondary sex char. score[b]	**	3.3 ± .2[i]	3.5 ± .2[i]	7.3 ± .2[j]	7.6 ± .2[j]	7.5 ± .2[j]
Marbling score[c]	**	9.3 ± .3[i]	8.4 ± .3[j]	6.6 ± .3[k]	6.4 ± .3[k]	6.3 ± .3[k]
Final maturity score[d]	**	2.3 ± .08[i]	2.4 ± .08[i]	2.9 ± .08[j]	2.7 ± .08[j]	2.7 ± .08[j]
Lean color score[e]	*	4.6 ± .1[i]	4.5 ± .1[i]	4.3 ± .1[ij]	4.2 ± .1[j]	4.5 ± .1[i]
Lean texture score[f]	**	5.7 ± .2[i]	5.7 ± .2[i]	5.3 ± .2[j]	4.9 ± .2[j]	4.9 ± .2[j]

[a]Adjusted for differences in date of birth; est. = estimated; KPH = kidney, pelvic, and heart.
[b]Char. = characteristics; 8 = high degree of masculinity, 5 = medium degree of masculinity, 2 = small degree of masculinity.
[c]11 = small-, 8 = slight-, 5 = traces-, 2 = practically devoid.
[d]1 = A-, 2 = A°, 3 = A+, 4 = B-, 5 = B°, 6 = B+.
[e]1 = very dark red, 2 = dark red, 3 = moderately dark red, 4 = slightly dark red, 5 = cherry red, 6 = very light cherry red, 7 = light grayish red (pink).
[f]1 = very coarse, 2 = coarse, 3 = moderately coarse, 4 = slightly coarse, 5 = slightly fine, 6 = moderately fine, 7 = very fine.
[g]Implanted in ear at days 0 and 70 with 36 mg of zeranol.
[h]Implanted in ear at days 0 with 72 mg of zeranol.
[ij]Values having no superscript letter in common differ at P≤.05 level.
*P<.05.
**P<.01.

Table 11.—Least-squares means and standard errors for carcass traits - experiment II

Traits	Level of signif-icance[b]	Treatment			
		Castrate	Intact	Scrotal implant	Ear implant
Hot carcass weight, lb	**	697 ± 12.6[i]	763 ± 13.4[j]	732 ± 12.3[j]	747 ± 13.4[j]
Dressing percentage	NS	60.2 ± .69	61.6 ± .74	60.0 ± .68	61.6 ± .74
Adjusted hot carcass weight[a], lb	**	697 ± 9.3[i]	763 ± 9.7[j]	741 ± 9.0[k]	750 ± 9.9[jk]
Adjusted fat thickness[ab], in	**	.38 ± .02[i]	.22 ± .02[j]	.23 ± .02[j]	.22 ± .02[j]
Longissimus area, in[2ab]	*	12.2 ± .26[i]	13.9 ± .28[j]	14.6 ± .25[j]	14.7 ± .28[j]
Est. KPH fat[a], percent	**	2.5 ± .08[i]	1.8 ± .08[j]	1.8 ± .08[j]	1.9 ± .08[j]
Est. cutability, percent	**	61.1 ± .28[i]	64.5 ± .30[j]	64.6 ± .28[j]	65.0 ± .30[j]
Est. retail product, percent	**	75.2 ± .34[i]	79.2 ± .37[j]	79.3 ± .34[j]	79.8 ± .37[j]
Secondary sex characteristics score[c]	NS	3.7 ± .3	6.3 ± .3	5.7 ± .3	6.7 ± .3
Marbling score[d]	NS	8.4 ± .39	6.2 ± .43	6.6 ± .38	5.7 ± .42
Final maturity score[e]	NS	2.5 ± .10	2.8 ± .10	2.7 ± .09	2.9 ± .10
Lean color score[f]	NS	4.4 ± .1	4.2 ± .1	4.0 ± .1	4.1 ± .1
Lean texture score[g]	NS	5.7 ± .2	5.3 ± .2	4.5 ± .2	4.6 ± .2

[a]Adjusted for differences in date of birth; Est. = estimate; KPH = kidney, pelvic, and heart.
[b]Determined at the 12th rib.
[c]8 = high degree of masculinity, 5 = medium degree of masculinity, 2 = small degree of masculinity.
[d]11 = small, 8 = slight, 5 = traces, 2 = practically devoid.
[e]1 = A−, 2 = A°, 3 = A+, 4 = B−, 5 = B°, 6 = B+.
[f]1 = very dark red, 2 = dark red, 3 = moderately dark red, 4 = slightly dark red, 5 = cherry red, 6 = very light cherry red, 7 = light grayish red (pink).
[g]1 = very coarse, 2 = coarse, 3 = moderately coarse, 4 = slightly coarse, 5 = slightly fine, 6 = moderately fine, 7 = very fine.
[h]NS = not significant; * P<.05; ** P<.01.
[ij]Means within rows with no superscript in common differ (P<.05).

derness, amount of connective tissue, and ease of fragmentation than longissimus muscle from intact males (Table 12). Intact males implanted with zeranol (two treatments) generally did not differ from each other nor from untreated intact males in either composition or palatability characteristics (Table 12). Neither fat percentage nor marbling score of the longissimus muscle were significantly associated with any of the characteristics relating to meat palatability. Sensory panel scores for amount of connective tissue and ease of fragmentation were highly associated (P<.01) with each other (r = .95) and with sensory panel score for tenderness (r = .95 and .96); the relationship of each of these three variables with shear force value was approximately equal (r = −.52, −.53, and −.55).

General. Animals on both experiments continued to consume feed and water and to gain weight immediately following castration; they gained weight during the 11 days following castration. Even though emasculator and surgically castrated animals did not differ in rate of gain, discomfort was believed to be less in the males castrated by emasculation. In experiment I, one surgically castrated animal died as a result of infection. Based on observations at slaughter, castration was complete in all males castrated by emasculation. These results suggest that castration may be delayed until 13 months of age in order to take advantage of the increased rate and efficiency of gain of intact males. Differences between intact males and late castrate (13 months) males in meat palatability characteristics were of about the same magnitude as has been reported between intact males and males castrated at a young age. Thus, these results suggest that castration may be delayed until about one year of age while obtaining meat palatability characteristics similar to early castrate males provided castration is followed by a long feeding period on a diet with high energy density.

Table 12.—Least-squares means and standard errors for meat traits by treatment and breed group

Traits	Level of signif-icance[h]	Treatment			
		Castrate	Intact	Intact 36-mg implant	Intact 72-mg implant
Fat in longissimus muscle, percent	**	3.1 ± .21[i]	2.2 ± .17[j]	2.8 ± .23[ik]	2.4 ± .23[jk]
Water in longissimus muscle, percent	NS	74.1 ± .28	74.2 ± .22	74.0 ± .30	74.3 ± .30
Protein in longissimus muscle, pct	NS	22.8 ± .24	23.6 ± .19	23.2 ± .26	23.3 ± .26
Marbling score[a]	**	8.1 ± .40[i]	6.5 ± .31[j]	6.8 ± .42[j]	5.9 ± .43[j]
Warner-Bratzler shear force[b], lb	**	7.9 ± .20[i]	8.8 ± .16[ij]	9.5 ± .21[j]	10.4 ± .21[j]
Juiciness score[c]	NS	5.3 ± .18	5.6 ± .14	5.6 ± .19	5.4 ± .19
Overall tenderness score[d]	**	6.0 ± .18[i]	5.5 ± .15[j]	5.2 ± .20[j]	5.0 ± .20[j]
Flavor intensity score [e]	*	5.8 ± .11[i]	5.7 ± .10[i]	5.8 ± .12[i]	5.4 ± .12[j]
Amount of connective tissue score[f]	**	5.6 ± .18[i]	5.3 ± .14[ij]	4.9 ± .19[j]	4.7 ± .19[j]
Ease of fragmentation score[g]	**	5.9 ± .17[i]	5.5 ± .14[ij]	5.1 ± .19[j]	4.9 ± .19[j]

[a]Practically devoid- = 2, traces- = 5, slight- = 8, small- = 11.
[b]Lb/.5 in^2.
[c]8 = extremely juicy, 7 = very juicy, 6 = moderately juicy, 5 = slightly juicy, 4 = slightly dry, 3 = moderately dry, 2 = very dry, 1 = extremely dry.
[d]8 = extremely tender, 7 = very tender, 6 = moderately tender, 5 = slightly tender, 4 = slightly tough, 3 = moderately tough, 2 = very tough, 1 = extremely tough.
[e]8 = extremely intense, 7 = very intense, 6 = moderately intense, 5 = slightly intense, 4 = slightly bland, 3 = moderately bland, 2 = very bland, 1 = extremely bland.
[f]8 = none, 7 = practically none, 6 = traces, 5 = slight, 4 = moderate, 3 = slightly abundant, 2 = moderately abundant, 1 = abundant.
[g]8 = extremely easy, 7 = very easy, 6 = moderately easy, 5 = slightly easy, 4 = slightly difficult, 3 = moderately difficult, 2 = very difficult, 1 = extremely difficult.
[h]NS = not significant.
[ik]Values having no superscript letter in common differ at P≤.05 level.
*P<.05.
**P<.01.

Heritability Estimates and Adjustment Factors for Yearling Testicular Size in Different Breeds of Beef Bulls

Donald D. Lunstra, Keith E. Gregory, and Larry V. Cundiff[1]

Introduction

Little information is available on breed differences and variation in testicular development of young beef bulls. Larger testis size in young bulls is favorably correlated with sperm output, age at puberty, mature testicular size, and pregnancy rate. If testicular size is to be considered in selection programs for young sires, the breed differences, heritabilities, and relationships of testicular measurements to age and body weight must be established for young beef bulls.

The objectives of this study were to measure and define breed differences and variations in testicular size of yearling beef bulls, determine the heritability of yearling testicular size, and to examine the relationships between testicular size and age, growth traits, and age-of-dam effects in yearling beef bulls.

Procedure

Data were collected on a total of 3,090 yearling beef bulls of 12 breed groups finishing growth-performance tests in 1979 through 1983. Breeds were Limousin (L), Hereford (H), Charolais (C), Angus (A), Red Poll (R), Simmental (S), Pinzgauer (P), Brown Swiss (B), Gelbvieh (G), and three composite populations of the following breed composition: Composite I (1/4 L, 1/4 B, 1/4 C, 1/4 HxA), Composite II (1/4 G, 1/4 S, 1/4 H, 1/4 A), and Composite III (1/4 P, 1/4 R, 1/4 H, 1/4 A). All bulls were born as contemporaries in early spring of each year, weaned at approximately 200 days of age, and placed on a growth-performance test through 368 days of age. Birth weight, weaning weight, and 228-, 284-, 340-, and 356-day weights were recorded. At approximately one year of age (354.0 ± .4 days of age), scrotal circumference, length of each testicle, body weight, and hip height were measured on all bulls.

Scrotal circumference (SC) was assumed to represent the circumference of two apposed circles of equal radius (r), using the formula $SC = 4r + 2\pi r$. Average testicular length (average TL) was calculated by adding left TL and right TL and dividing by two. Paired testicular volume (PTV), assuming each testicle was a prolate spheroid, was then calculated using the formula:

$$PTV = .0396125 \text{ (Average TL)}(SC)^2$$

Data were analyzed by least squares procedures using a model that included breed group, sire/breed group, year, age of dam, and appropriate interactions. Paternal half-sib analysis (307 sires with approximately ten sons per sire) was used to estimate genetic parameters. Data expressed on an age-constant or weight-constant basis were adjusted to 354 days of age or to 919 lb liveweight (average of all bulls at yearling measurement) using the appropriate linear regression coefficients within breed group.

Results

Number of bulls per breed group and the least-squares breed group means and heritability estimates for body weight and hip height are shown in Table 1. Least-squares breed group means and heritability estimates for scrotal circumference, average testicular length, and paired testicular volume are given in Table 2. Breed group, sire/breed group, year, and age-of-dam effects were highly significant for all traits at a constant age (354 days) and constant body weight (919 lb), except that age-of-dam had no significant effect ($P>.25$) on hip height at constant body weight. Paternal half-sib estimates of heritability (h^2 ± SE) were high for age constant testicular traits, particularly for scrotal circumference (.41 ± .06). The lower heritability estimates for testicular length probably reflect experimental procedure rather than biological fact, since testicular length was more difficult to measure accurately than was scrotal circumference, and repeatability of scrotal circumference measurements is very high (>.90). The heritability estimate for scrotal circumference is in good agreement with the heritabilities of .26 to .78 reported for young Holstein bulls between 6 and 17 months of age and the .40 ± .15 to .69 ± .15 reported for beef bulls in other studies. Heritability estimates were slightly, but not significantly, higher for weight-constant testicular traits than for age-constant traits. Since body weight varied considerably at 354 days of age, weight-constant traits were adjusted to a much greater extent and may be less reliable estimates of heritability than are age-constant estimates.

Scrotal circumference, average testicular length, and paired testicular volume were larger ($P<.01$) for Pinzgauer, Simmental, Brown Swiss, and Gelbvieh than for other pure breeds and were smaller ($P<.01$) for Limousin and Hereford than for all other breed groups at 354 days of age (Table 2). The ranking of purebred means for scrotal circumference (Table 2) was similar to the rankings of Limousin, Hereford, Charolais, Angus, and Simmental that have been reported in other studies. Although significant breed differences existed (Table 2), considerable variation in these testicular traits existed within each breed. The range within each breed was large enough that the range for Limousin bulls overlapped that of Gelbvieh and that of all intermediate pure breeds. This variation, coupled with the relatively high estimates of heritability for testicular traits, indicates that rapid improvement in yearling testicular size can be achieved by selection. Such selection should also result in rapid improvement in age at puberty and favorably affect other reproductive characteristics.

Age-constant genetic and phenotypic correlations between a variety of body growth traits and testicular traits in yearling beef bulls were generally positive but were relatively small (Table 3). Those genetic correlations that were negative had values that were essentially equal to zero. The linear effects of age and yearling body weight each affected testicular traits when analyzed as separate covariates ($P<.001$), but age continued to have a highly significant effect on testicular traits when adjusted for body weight. These data suggest that adjustment of testicular traits for age differences would be more important than adjustment for differences in growth traits, both among and within breeds of yearling beef bulls. These results also indicate that body growth traits and testicular size in yearling beef bulls are favorably related, genetically, but the low level of the relationship indicates that testicular size and body weight are largely independent (Table 3). In other words, selection of beef bulls for growth traits would have little effect on yearling testicular size, and selection for testicular size would have little effect on yearling weight.

Age of dam had a significant effect on age-constant testicular traits of yearling beef bulls (Table 4), and testicular size increased as age of dam increased. The effect of age of dam on testicular traits remained significant after adjustment of data to a constant body weight, which should have corrected for documented age-of-dam effects, such as differences due to lactation. Testicular size of yearling beef bulls from two-year-old dams was smaller, on an age-constant ($P<.01$) and weight-

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constant ($P<.05$) basis, than that of bulls from older dams, suggesting that testicular development is delayed by undefined *in utero* or preweaning factors influencing the male offspring of first-calf dams. Age-of-dam effects on testicular traits were similar among the breed groups examined in this study, indicating that a single adjustment for age of dam should be appropriate, regardless of breed.

Bull age at the time that yearling testicular measurements were obtained ranged from 300 to 400 days of age in this study. Adjustment factors that we recommend for testicular traits of beef bulls within that age range are shown in Table 5. To adjust a testicular trait to 365 days of age, the linear regression coefficients for scrotal circumference (cm/day), average testicular length (cm/day), and paired testicular volume (cm^3/day) are given, since they offer a simple, yet effective, method for adjusting testicular size to a constant age. The linear regression coefficients for testicular traits were uniformly positive in all breed groups. However, least-squares analysis of variance indicated no significant difference among breeds in their linear regression coefficients for these testicular traits. Therefore, we recommend using only the adjustment factor (linear regression coefficient) shown for "all bulls", regardless of breed, rather than using any of the adjustment factors shown for individual breed groups (Table 5). The age-of-dam adjustment factors are not multiplicative, and these age-of-dam constants should be added to the testicular trait only after the trait has been adjusted to 365 days of age (Table 5).

Table 1.—Least-squares means and heritability (h^2) estimates for body weight and hip height of yearling beef bulls

Breed group	No. of bulls	Body weight[a] (lb; SE = ± 7) 354 days	Hip height[b] (in; SE = ± 0.1) 354 days	919 lb
Limousin	222	875	49.1	49.6
Hereford	256	791	45.2	46.7
Charolais	197	993	50.3	49.5
Angus	449	825	45.8	46.9
Red Poll	222	835	47.2	48.1
Pinzgauer	144	959	48.8	48.3
Simmental	238	1009	50.8	49.8
Brown Swiss	245	964	50.3	49.8
Gelbvieh	233	970	50.0	49.5
Composite I	245	971	49.6	49.1
Composite II	488	967	48.7	48.2
Composite III	151	924	47.8	47.7
h^2 ± SE	(3,090)[c]	.32 ± .05	.28 ± .05	.34 ± .06

[a]Breed means that differ by >35 lb body weight are different ($P<.01$).
[b]Breed means that differ by >.4 in hip height are different ($P<.01$).
[c]Total bulls represented 307 sires with approxmiately 26 sires/breed group and sons/sire.

Table 2.—Least-squares means and heritability (h^2) estimates for scrotal circumference (SC), average testicular length (TL), and paired testicular volume (PTV) of yearling beef bulls[a]

Breed group	SC (cm; SE = ±.3) 354 days	919 lb	Ave. TL (cm; SE = ±.1) 354 days	919 lb	PTV (cm^3; SE = ±10) 354 days	919 lb
Limousin	28.8	29.1	9.5	9.7	318	337
Hereford	30.1	32.1	9.4	10.2	342	410
Charolais	31.4	30.4	10.0	9.5	401	358
Angus	31.9	33.2	10.3	10.8	421	474
Red Poll	32.3	33.5	10.2	10.6	427	476
Pinzgauer	33.4	33.0	10.9	10.7	488	473
Simmental	33.4	32.4	11.1	10.8	497	456
Brown Swiss	33.5	32.9	11.4	11.1	512	485
Gelbvieh	33.6	32.9	11.2	11.0	509	479
Composite I	32.2	31.7	10.9	10.7	456[b]	435
Composite II	33.5	33.3	11.3	11.1	519[b]	496
Composite III	33.4	33.3	10.7	10.7	476[b]	474
h^2 ± SE	.41 ± .06	.50 ± .06	.34 ± .06	.39 ± .06	.37 ± .06	.45 ± .06

[a]Breed means that differ by >1.0 cm (SC), >.3 cm (Ave. TL), or >48 cm^3 (PTV) are different ($P<.01$).
[b]The effect of heterosis on age-constant PTV was +13.1 percent, +17.4 percent and +13.3 percent in Composite I, II, and III, respectively.

Table 3.—Genetic and phenotypic correlations between body weight traits during development and age-constant (354 days) testicular traits

Body weight trait	Yearling testicular trait: Scrotal circumference	Ave. testicular length	Paired testicular volume
	Genetic correlations		
Birth weight	−.02 ± .10	−.01 ± .11	−.05 ± .11
Weaning weight	.00 ± .10	.19 ± .10	.11 ± .10
AGD (Birth to weaning)[a]	.02 ± .11	.21 ± .11	.14 ± .11
Yearling weight	.10 ± .11	.16 ± .11	.14 ± .12
ADG (weaning to yearling)[a]	.00 ± .10	−.02 ± .11	−.04 ± .11
	Phenotypic correlations		
Birth weight	.10	.08	.11
Weaning weight	.26	.24	.28
ADG (Birth to weaning)[a]	.25	.24	.28
Yearling weight	.33	.28	.34
ADG (Weaning to yearling)[a]	.20	.15	.19

[a]Average daily gain (ADG).

Table 4.—Age-of-dam means for testicular traits of yearling beef bulls

Age of dam (yr)	No. of bulls	Yearling testicular trait: Scrotal circumference (cm)	Ave. testicular length (cm)	Paired testicular volume (cm^3)
		Age constant (354 days)		
2	831	31.6 ± .1	10.2 ± .1	415 ± 6
3	757	32.1 ± .1[a]	10.6 ± .1[a]	443 ± 5[a]
4	502	32.5 ± .1[a]	10.7 ± .1[a]	460 ± 6[a]
>4	1,000	32.9 ± .1[a]	10.8 ± .1[a]	471 ± 5[a]
>2	2,259	32.6 ± .1[a]	10.7 ± .1[a]	459 ± 4[a]
Total	3,090	32.3 ± .1	10.6 ± .1	447 ± 3
		Weight constant (919 lb)		
2	831	32.1 ± .1	10.4 ± .1	433 ± 6
3	757	32.3 ± .1	10.6 ± .1[b]	446 ± 5
4	502	32.4 ± .1[b]	10.7 ± .1[b]	452 ± 6[b]
>4	1,000	32.6 ± .1[b]	10.6 ± .1[b]	454 ± 5[b]
>2	2,259	32.5 ± .1[b]	10.6 ± .1[b]	451 ± 4[b]
Total	3,090	32.3 ± .1	10.6 ± .1	446 ± 4

[a] [b]Means within a column differ from the mean of bulls from 2-year-old dams ([a]P<.01; [b]P<.05).

Table 5.—Adjustment factors for the effects of bull age and age of dam on testicular traits in yearling beef bulls between 300 and 400 days of age

Adjustment	Adjustment factors for testicular traits: Scrotal circumference	Ave. testicular length	Paired testicular volume
For bull age[a]:	(±SE per breed group = ±.012)	(±SE per breed group = ±.006)	(±SE per breed group = ±.40)
Limousin	.026 cm/day	.014 cm/day	1.13 cm^3/day
Hereford	.036	.012	1.26
Charolais	.013	.009	.73
Angus	.034	.013	1.44
Red Poll	.035	.016	1.59
Pinzgauer	.034	.017	1.65
Simmental	.034	.011	1.54
Brown Swiss	.032	.014	1.59
Gelbvieh	.026	.006	1.06
Composite I	.054	.021	2.25
Composite II	.030	.013	1.62
Composite III	.028	.012	1.32
All bulls[b]	.032 cm/day	.013 cm/day	1.43 cm^3/day
For age of dam[c]:			
5-yr or older dams	+ 0.0 cm	+ 0.0 cm	+ 0 cm^3
4-yr-old dams	+ 0.4 cm	+ 0.1 cm	+ 11 cm^3
3-yr-old dams	+ 0.8 cm	+ 0.2 cm	+ 28 cm^3
2-yr-old dams	+ 1.3 cm	+ 0.6 cm	+ 56 cm^3

[a]Adjusment factors are linear regression coefficients (cm or cm^3 per day of age).

[b]Use of this adjustment factor (linear regression coefficient) only, regardless of breed, is recommended. Use the following formula to adjust a trait to 365 days of age: Adjusted testicular trait = [(Adjustment factor) (365 − Actual bull age in days) + (Actual measurement)].

[c]These age-of-dam constants should be added to the testicular trait only after the trait has been adjusted to 365 days of age.

Effect of Single-Sire and Multiple-Sire Natural Mating on Pregnancy Rate of Beef Cattle

Donald D. Lunstra[1]

Introduction

Although artificial insemination (AI) is widely used in dairy cattle, AI has found only limited application in beef cattle. Use of bulls in natural mating programs accounts for more than 95 percent of the pregnancies achieved each year in the U.S. beef cattle industry. Success of such natural mating programs depends on the reproductive capacity and fertility of the individual herd sires used, but very little research on the natural mating fertility of beef bulls has been conducted. Because of the general lack of information on effective techniques for identifying sires with superior fertility, procedures currently used for selecting herd sires for natural mating are based on factors other than reproductive potential and include factors (such as body wt, growth rate, appearance, etc.) that have little relationship to bull fertility. It is not surprising that a large range in pregnancy rate of beef bulls used in single-sire natural mating has been reported, and commercial cattle producers have resorted to using multiple sires in pasture breeding, assuming that more fertile bulls compensate for less fertile bulls within multiple-sire groups. Conflicting reports exist in the available literature, with some results indicating that pregnancy rate may be higher during multiple-sire mating than during single-sire mating, while other reports indicate that pregnancy rates are not improved by multiple-sire breeding. Studies using AI indicate that increasing the number of inseminations per estrous female increases pregnancy rate, and that inseminating mixtures of semen from two or more bulls generally increases pregnancy rate. However, it is unknown if increasing the number of services per female or increasing the number of sires servicing each female results in increased pregnancy rate in natural mating programs.

This report presents results of a study conducted to determine the effect of number of services on natural-mating pregnancy rate and to investigate the effect of multiple-sire natural mating on pregnancy rate in beef cattle.

Procedure

Twelve mature Angus bulls, 3 to 5 years of age, possessing acceptable semen quality and normal testicular size, were selected for use in breeding trials. Bulls were assigned letters A through L for the duration of the study, and the letter was painted prominently (24 in height) on each side of the bull for ease of identification. Bulls were examined and two semen samples collected and evaluated 2 wk before the beginning of the 60-day breeding period. The study was designed so that each bull was used every other day, and each bull completed seven services with five different estrous females every six days throughout the 60-day breeding period (Table 1).

To obtain females in estrus, 560 cyclic crossbred heifers averaging 16 months of age were observed for estrus twice daily for 60 days (7:00 a.m. and 7:00 p.m.). Six heifers exhibiting the strongest estrous behavior were selected daily (8:00 a.m.) from those heifers first detected in estrus that morning. The six heifers were placed in holding pens, and all scheduled services (Table 1) were completed within a 30 min time frame/heifer. Each estrous heifer received (1) one service by one bull (single-sire, single-service = SSSS), (2) three services by one bull (single-sire, multiple-service = SSMS), or (3) one service by each of three different bulls (multiple-sire, multiple-service = MSMS) according to the schedule shown in Table 1. For MSMS, bulls were used as four subgroups of three bulls each (ABC, DEF, GHI, and JKL). While the original goal was to obtain 120 SSSS, 120 SSMS, and 120 MSMS mated heifers (360 heifers total), a total of 352 mated heifers (124 SSSS, 105 SSMS, and 123 MSMS) was achieved. This difference was due to natural variation in number of heifers in estrus on the morning of each day (occasionally less than six during the last 30 days of the study) and to low receptivity in some heifers (occurred most often in heifers scheduled for SSMS). After mating, heifers were placed in a separate pasture and pregnancy palpated at approximately 60 days postmating.

Results

Average pregnancy rates of heifers mated by only one bull were essentially the same, regardless of whether heifers received one service (SSSS, 62.1 pct) or three services (SSMS, 62.9 pct) per bull (Table 2). These results indicate that increasing the number of services/female in single-sire matings did not increase pregnancy rate. However, all services were completed within a 30 min time frame/estrous female, and distributing services over a longer time frame (several hours) may increase pregnancy rate, although this effect was not tested in this study. For multiple-sire matings, average pregnancy rate of heifers mated by three bulls (MSMS, 74.0 pct) was 11 to 12 percent greater and significantly higher than the average pregnancy rate of heifers mated once (SSSS) or three times (SSMS) by only one bull. The range in pregnancy rate among subgroups of bulls used for multiple-sire matings was relatively small (ranged from 68 to 84 pct). In contrast, the range among bulls (0 to 95 pct) and among subgroups of bulls (49 to 80 pct) was much larger when used for single-sire matings. These data indicate that use of multiple sires in breeding programs should result in an increased average pregnancy rate/estrous female and less variation in pregnancy rate/multiple-sire pasture than could be achieved with single-sire breeding programs.

The large range in pregnancy rate among bulls used for single-sire matings (0 to 95 pct) offered an opportunity to study possible interrelationships to variation in testis size and semen quality. However, only low correlations were found between bull fertility (pregnancy rate) and scrotal circumference ($r = .39$, $P < .11$), percent motile sperm ($r = .13$, nonsignificant), percent abnormal sperm ($r = -.43$, $P < .10$), and percent sperm with intact acrosomes ($r = .48$, $P < .07$). These results indicate that considerable variation in single-sire fertility rate can be expected, even among bulls with acceptable testicular size and normal semen quality. However, the variation in fertility rate was reduced and average pregnancy rates were increased significantly when these same bulls were used for multiple-sire mating.

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Table 1.—Design of single-service *vs* multiple-service and single-sire *vs* multiple-sire pregnancy rate study[a]

Day of schedule[a]	Bulls used per day[b]	Number of services required per bull used per day[c]	Type of mating estrous female[d]: Single-sire, single-service (SSSS)	Single-sire, multiple-service (SSMS)	Multiple-sire, multiple-service (MSMS)	Total heifers mated per day[c e]
Single sire:[c]						
Day 1	A,B,C,D,E,F	1	1 (1)	- - - - -	- - - - -	6
Day 2	G,H,I,J,K,L	1	1 (1)	- - - - -	- - - - -	6
Day 3	A,B,C,D,E,F	3	- - - - -	1 (3)	- - - - -	6
Day 4	G,H,I,J,K,L	3	- - - - -	1 (3)	- - - - -	6
Multiple-sire:[c e]						
Day 5	AxBxC, DxExF	3	- - - - -	- - - - -	3 (1)	6
Day 6	GxHxI, JxKxL	3	- - - - -	- - - - -	3 (1)	6

[a]The design was based on a 6-day cycle which was repeated ten times. Total duration of experiment was 60 days.
[b]Twelve mature Angus bulls, 3 to 5 years of age, designated A through L, were used for mating.
[c]Each bull was used every other day. Each bull was required to complete seven services with five different estrous females during each 6-day cycle of the experiment.
[d]Number of heifers mated/bull used/day is given. Number of services/bull/estrous female is given in parentheses.
[e]For multiple-sire matings, bulls were randomly assigned to one of four 3-bull subgroups (AxBxC, DxExF, GxHxI, JxKxL). Each heifer identifed for multiple-sire mating received one service/bull from each of the three bulls in a subgroup.

Table 2.—Pregnancy rates of heifers mated single-service *vs* multiple-service and single-sire *vs* multiple-sire

Bulls in subgroup	Pregnancy rate (pct) and number of heifers per type of mating[a]: Single-sire mated: Single-service(SSSS)[b]	Multiple-service(SSMS)[b]	Combined (SSSS + SSMS)[b]	Range among bulls (pct)	Multiple-sire: Multiple-service(MSMS)[b]	All matings
A,B,C	80.0(30)	63.3(30)	71.7(60)	62 to 80 pct	69.0(29)	70.8(89)
D,E,F	50.0(34)	50.0(24)	50.0(58)	12 to 63 pct	83.9(31)[fhi]	61.8(80)
G,H,I	48.6(35)	68.4(19)[c]	55.6(54)	0 to 95 pct	67.7(31)[di]	60.0(85)
J,K,L	76.0(25)	68.8(32)	71.9(57)	61 to 77 pct	75.0(32)	73.0(89)
All bulls	62.1(124)	62.9(105)	62.4(229)	0 to 95 pct	74.0(123)[egi]	66.5(352)
Range among subgroups	49 to 80 pct	50 to 69 pct	49 to 80 pct	– – –	68 to 84 pct	49 to 84 pct

[a]Pregnancy rate is given as percent (pct pregnant = no. of heifers pregnant x 100/no. of heifers mated), and number of heifers mated is given in parentheses.
[b]Abbreviations: SSSS = single-sire, single-service mating; SSMS = single-sire, multiple-service mating (3 services by one bull/female); MSMS = multiple-sire, multiple-service mating (3 services/female via one service by each of the three bulls in a subgroup).
[c]Pregnancy rate for SSMS is higher ($P < .10$) than pregnancy rate for SSSS, within a row.
[d e f g h i]Pregnancy rate for MSMS is higher than for pregnancy rate for for SSSS ([d]$P < .05$, [e]$P < .05$, [f]$P < .01$), SSMS ([g]$P < .05$, [h]$P < .01$), and combined SSSS + SSMS ([i]$P < .05$, [i]$P < .01$) within a row.

Increasing Pregnancy Rate in Beef Cattle by Clitoral Massage During Artificial Insemination

Donald D. Lunstra, W. Gordon Hays, Robert A. Bellows, and Dan B. Laster[1]

Introduction

Clitoral massage (stimulation) at the time of artificial insemination (AI) has been reported to increase pregnancy rate in lactating beef cows, but not to increase pregnancy rate in heifers. These reports have been limited to studies conducted at one location in the U. S. (Miles City, Montana), and the efficacy of clitoral massage on AI pregnancy rates of beef cattle at other geographic locations has not been reported. To our knowledge, there are no reports in the literature indicating a negative effect of clitoral stimulation on pregnancy rate of cows.

The following experiment was conducted to test the effects of clitoral massage on pregnancy rate to artificial insemination in beef cattle and to define the effects of age, postpartum interval, and technician on pregnancy responses to clitoral massage performed at the time of artificial insemination.

Procedure

The experiment was conducted at MARC during the late spring breeding season. Pregnancy rate and service of conception were determined from calving data obtained approximately 9 months after insemination. Data were recorded for 596 heifers (1 to 1.5 yr old) and 1,260 cows (2 to 13 yr old), and the population included straightbred Angus, Hereford, Brown Swiss, Charolais, Red Poll, Limousin, Simmental, and crossbred Limousin x Gelbvieh x Hereford females. The breeding period consisted of 30 to 42 days for artificial insemination followed by a 21- to 33-day natural mating period. The design of the experiment is shown in Table 1. Frozen semen from 72 bulls was used for artificial insemination. The frozen semen was packaged in either ampules or straws, and recommended semen thawing and handling procedures were used throughout the study. Thawing and inseminations were performed by seven experienced technicians. Females, as detected in estrus, were randomly assigned within breed, age, and sire to receive either no massage or 3 sec of manual clitoral massage immediately following artificial insemination. Estrus was detected visually by observing female behavior twice daily (7 a.m. and 7 p.m.), and estrous females were inseminated once at approximately 12 h after detection of estrus.

Females were maintained on pasture adequate to allow weight gain throughout the breeding period, and pasture was supplemented with access to alfalfa hay from mid-gestation through calving.

Results

Data were analyzed using least squares analysis of variance with a model that included the effects of treatment, age, technician, breed, postpartum interval (prior to AI; cows only), and appropriate interactions. Treatment (clitoral stimulation *vs* nonstimulated), technician, age, and postpartum interval had significant effects on the AI pregnancy rates obtained, but breed of female had no effect.

Clitoral stimulation applied at the time of insemination had a significant positive influence on pregnancy rate of beef females at both first and second service (Table 2). The stimulation increased pregnancy rate in cows by 15 percent at first service (74 *vs* 59 pct) and 14 percent at second service (67 *vs* 53 pct). These results agree with other reports that have indicated an increase of between 6 and 15 percent in pregnancy rates of cows when clitoral massage of 3 to 10 seconds is applied at the time of insemination.

Clitoral stimulation had no beneficial effect ($P>.10$) on pregnancy rate of heifers at either first (53 *vs* 57 pct) or second service (62 *vs* 53 pct), Table 2. The lack of effect for clitoral massage in heifers is in agreement with results obtained at Miles City, Montana. Analyses revealed a significant age x treatment interaction for first-service pregnancy rates, reflecting the differential influence of clitoral stimulation on cow *vs* heifer pregnancy rates (i.e., pregnancy rate in cows was increased, while pregnancy rate in heifers tended to decrease in response to stimulation at first service), Table 2.

Treatment had a significant effect on second service pregnancy rate, but no other factor exhibited a significant effect at second service, probably due to the limited number of females that received a second insemination. The remainder of this discussion will concern results from analysis of first-service pregnancy rates only.

Total pregnancy rate achieved per technician ranged from 60 ± 4 to 68 ± 4 percent for all first service inseminations (Table 3). A significant treatment x technician interaction at first service indicated that some technicians were more effective at applying clitoral stimulation than others. Average pregnancy rate achieved per technician ranged from 49 to 67 percent in nonstimulated and from 58 to 79 percent in stimulated females

Table 1.—Number of females per treatment group[a]

Age	Clitoral treatment: Stimulated[b]	Clitoral treatment: Nonstimulated	Total
First service:			
Heifers	302	294	596
Cows	649	611	1,260
Total	951	905	1,856
Second service:			
Heifers	80	68	148
Cows	66	95	161
Total	146	163	309

[a]All females were subjected to artificial insemination at approximately 12 h after detection of estrus.
[b]Manual clitoral stimulation was applied for 3 sec immediately after insemination.

Table 2.—Least-squares means for pregnancy rate to artificial insemination with and without clitoral stimulation[a]

Age	Clitoral treatment: Stimulated[b]	Clitoral treatment: Nonstimulated	Total
First service:			
Heifers	53 ± 5	57 ± 5	55 ± 3
Cows	74 ± 3[b]	59 ± 3	66 ± 2
All females	69 ± 2[b]	59 ± 2	64 ± 1
Second service:			
Heifers	62 ± 6	53 ± 6	58 ± 4
Cows	67 ± 6	53 ± 5	60 ± 4
All females	64 ± 4[c]	53 ± 4	59 ± 3

[a]Values are x ± SE pregnancy rate (pct) from least squares analysis (first service, n = 1,856 females; second service, n = 309 females).
[b c]Pregnancy rates that are significantly higher than the pregnancy rate of nonstimulated females are indicated ([b]$P<.05$; [c]$P<.10$).

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at first service (Table 3). A negative (nonsignificant) effect of clitoral stimulation was noted for one technician (F), small increases (2 to 7 pct) were noted for three technicians (C, E and G), and relatively large increases (12 to 30 pct) in pregnancy rates of clitoral-stimulated *vs* nonstimulated females was noted for three of the seven technicians (A, B, and D). Other researchers have reported that stimulation of the cervix and vagina can influence uterine motility, timing of the luteinizing hormone surge, and timing of ovulation. Some technicians may have stimulated the female tract enough during insemination without clitoral stimulation that no improvement in pregnancy rate was noted when clitoral stimulation was applied.

Age of female influenced pregnancy rate to first service among cows subjected to clitoral stimulation (Table 4). Stimulated cows 3 to 4 years of age exhibited a significantly higher pregnancy rate (78 ± 4 pct) than did nonstimulated cows of the same age (59 ± 5 pct). Pregnancy rate of young cows (2 yr) and older cows (5 yr or older) also tended to be increased by clitoral stimulation (Table 4), although the amount of improvement was not as pronounced as that observed in cows 3 to 4 years of age (+12 and +10 pct *vs* +19 pct, respectively).

The tendency for increased pregnancy was observed, although not significant, among nonstimulated cows 3 to 4 years of age compared to younger cows. For total females, cows 2 years of age and cows 5 or more years of age tended to have lower pregnancy rates than did cows 3 to 4 years of age (Table 4). Clitoral stimulation had a positive effect on pregnancy rate in all cows, regardless of age. These data indicate that clitoral stimulation may be slightly more beneficial when applied to cows 3 to 4 years of age than when applied to cows of other ages.

Postpartum interval among cows in the study influenced pregnancy rate ($P<.01$) to first service, regardless of treatment (Table 5). Cows that had calved within 50 days of first service exhibited markedly lower ($P<.01$) pregnancy rates (48 ± 5 pct) than cows that had postpartum intervals exceeding 50 days (68 ± 3 pct). Clitoral stimulation increased pregnancy rate to first service across all postpartum intervals (Table 5). Pregnancy rate remained lower ($P<.10$) in stimulated cows with a postpartum interval of 50 days or less (57 ± 7 pct) than in stimulated cows with postpartum intervals exceeding 50 days (74 ± 4 pct), but there was a significant improvement (+18 pct) due to clitoral stimulation even in the short postpartum group (57 *vs* 39 pct). Clitoral stimulation appeared to be a useful method for improving pregnancy rate in cows, regardless of postpartum interval.

The mechanism by which clitoral stimulation causes an increased pregnancy rate in cows and a differential effect in heifers *vs* cows is unknown. It is known that uterine motility is increased in cows during exposure to a bull, nuzzling of genitalia, mounting, and copulation, and these factors may increase pregnancy rate by improving sperm transport. It is also known that either manual stimulation of the clitoris or natural service by a bull shortens the interval from onset of estrus to ovulation in cows, perhaps creating a better timing between insemination and ovulation. It is not known if heifers respond differently to these stimuli than do cows. Further studies are needed before these questions can be answered.

Table 3.—Influence of technician on first service pregnancy rate to artificial insemination with and without clitoral massage

	Clitoral stimulation			No clitoral stimulation		Total females	
Technician	n	Pregnant[a]	†[b]	n	Pregnant[a]	n	Pregnant[a]
A	180	73 ± 5	+20	177	53 ± 6	357	63 ± 4
B	105	79 ± 7	+30	100	49 ± 7	205	64 ± 5
C	195	64 ± 4	+ 2	187	62 ± 4	382	63 ± 3
D	135	72 ± 5	+12	127	60 ± 6	262	66 ± 4
E	119	68 ± 6	+ 7	119	61 ± 6	238	64 ± 4
F	131	58 ± 5	− 4	116	62 ± 5	247	60 ± 4
G	86	70 ± 6	+ 3	79	67 ± 6	165	68 ± 4
Total	951	69 ± 2	+10	905	59 ± 2	1,856	64 ± 1

[a]Values are least squares x ± SE first service pregnancy rate (pct) for all females inseminated, regardless of age (n = 1,856).
[b]Differences (†) between pregnancy rate achieved with clitoral stimulation and that achieved without clitoral stimulation.

Table 4.—Influence of age at first service on pregnancy rate to artificial insemination with and without clitoral massage

	Clitoral stimulation		No clitoral stimulaion		Total females	
Age at insemination	n	Pregnant[a]	n	Pregnant[a]	n	Pregnant[a]
Heifers:						
1.0-1.5 yr	302	53 ± 5	294	57 ± 5	596	55 ± 3
Cows:						
2.0 yr	119	68 ± 6	119	56 ± 5	238	62 ± 4
3.0 yr	159	79 ± 4[c]	155	59 ± 4	314	69 ± 3
4.0 yr	96	75 ± 5[b]	90	60 ± 6	186	68 ± 4
≥5.0 yr	275	69 ± 4	247	59 ± 4	522	64 ± 3
All cows	649	74 ± 3[c]	611	59 ± 3	1,260	66 ± 3

[a]Values are x ± SE first service pregnancy rates (pct) after least squares analysis (n = 1,856).
[b c]Pregnancy rates that differ significantly from the pregnancy rates of females receiving no clitoral stimulation are indicated ([b]$P<.10$; [c]$P<.05$).

Table 5.—Influence of postpartum interval at first service on pregnancy rate to artifical insemination with and without clitoral stimulation in cows

Postpartum interval	Clitoral stimulation		No clitoral stimulation		Total cows	
	n	Pregnant[a]	n	Pregnant[a]	n	Pregnant[a]
20 to 50 days	65	57 ± 7[b]	59	39 ± 7	124	48 ± 5
51 to 75 days	183	76 ± 5[b]	177	59 ± 5	360	68 ± 4
76 to 100 days	232	77 ± 5[b]	201	62 ± 5	433	70 ± 3
⩾ 101 days	169	69 ± 5	174	62 ± 4	343	66 ± 3
Total	649	70 ± 4[c]	611	56 ± 4	1,260	62 ± 3

[a]Values are x ± SE first service pregnancy rates (pct) after least squares analysis of all cows that had calved prior to application of treatment (n = 1,260).

[b c]Pregnancy rates that differ significantly from the pregnancy rates of females receiving no clitoral stimulation are indicated ([b]P<.10; [c]P<.05).

Causes and Influences of Repeat Breeding in Beef Cattle

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Introduction

Repeat-breeding females were classified as those females nonpregnant after two consecutive breeding seasons of 45 to 60 days' duration. Females were either naturally mated or artificially inseminated and exposed to clean-up bulls. Each year, approximately 7,000 beef females (6,803 to 7,374) at the Research Center were bred by either artificial insemination (approximately 2,000 females) and/or exposure to single or multiple sires in two breeding periods of 45 to 60 days' duration. Breeding periods were either May 15 to July 15 or November 1 to December 31 during 1979 through 1982. During the four years, 165 heifers and 241 cows (clinically free of diseases and 2 to 12 yr of age) of various straight and crossed breeds were classified as repeat breeders. Contemporary cows (102 head, clinically free of diseases and 3 to 11 yr of age) of various straight and crossed breeds, which produced a calf in the previous calving season, served as controls. Statistics on conception rate, calf survival, and number of repeat breeders are listed in Table 1. Total calf crop loss (28 pct average over four yr) resulted from 52 percent of the females being open (not pregnant) at palpation, while 48 percent of the females were pregnant but had prenatal (9.0 pct) and postnatal (39 pct) losses. The percentage of females classified as repeat breeders from the total females exposed was low (1.0 to 1.7). However, the percentage of females classified as repeat breeders from those females palpated nonpregnant averaged 10. Although repeat breeding was not a big problem in the Research Center herds, it may be a problem in other herds. Various causes and influences were investigated in the 406 repeat breeders in an attempt to determine if repeat breeding was due to one or several causes. Factors investigated in the beef cows and heifers were: previous calving difficulty in cows, fertilization failure, embryonic mortality, hormonal dysfunction, chromosomal abnormalities, and uterine secretions.

Procedure

At each parturition, a calving difficulty score was assigned to each cow. Therefore, records from cows which were classified as repeat breeders and controls were analyzed for calving difficulty score, weaning percentage, and calving efficiency. The scoring system for calving difficulty is shown in Table 2. Percentage parturition difficulty was calculated by counting the number of calving difficulty scores of 3 or more and dividing by the number of parturitions per cow, multiplied by 100. Percentage abnormal presentation or posture was calculated by counting the number of calving scores of 8 divided by the number of parturitions per cow, multiplied by 100. Percentage calves weaned equaled number of calves weaned divided by total calves born per cow, multiplied by 100. Percentage calving efficiency equaled number of calves per cow divided by cow-age-minus-1, multiplied by 100.

Before slaughter all repeat-breeder and control females were placed with multiple sires of either the Charolais or Simmental breed and mated. Estrous behavior was observed twice daily from 7 to 9 a.m. and 4 to 6 p.m. All females were slaughtered on days 2 to 51 postmating and their reproductive tracts collected for anatomical information, pregnancy determination, and uterine secretions. Blood samples were collected at days 3, 6, or 9 in the same females or at either days 3, 6, or 9 in different females. In a smaller group of controls (5) and repeat breeders (6), more frequent blood samples were collected, starting from estrus until slaughter at days 8 to 10. The blood serum was analyzed for progesterone, estradiol-17β, and luteinizing hormone concentration using radioimmunological procedures.

Preimplanted and early attached embryos were flushed from the oviduct and uterine horn ipsilateral (same side) to the corpus luteum using physiological saline or phosphate-buffered saline. The flushings were searched for an oocyte or embryo. Upon finding an oocyte or embryo, it was examined for fertilization and/or morphological development and classified as normal developing embryo, degenerate or degenerating embryo, or unfertilized oocyte. If no oocyte or embryo was found, the female was designated as a "nonrecovery" female. The uterine flushings from females less than 25 days into gestation were analyzed for protein, zinc, and calcium content. Fetuses 25 days or older were dissected from the uterine horn and examined for normal development.

In 133 repeat-breeder females, a jugular vein blood sample was collected in heparinized syringes. Peripheral blood lymphocytes were cultured, and chromosome metaphase spreads were prepared. The metaphase spreads were examined for chromosomal abnormalities under the microscope at 650X or higher magnification.

Results

More parturition (calving) difficulties ($P<.05$) were found in the repeat breeders (194/639 = 30.4 pct) than controls (57/392 = 14.5 pct) Table 2. The percentage of parturition difficulties did not differ when each group was heifers (first calving) as calving difficulty percentage was 133/241 = 47.6 and 47/102 = 46.1, respectively, for the repeat breeders and controls. The repeat breeders (61/398 = 15.3 pct) had 4.5 times more difficulties with subsequent parturitions than controls (10/290 = 3.4 pct). Besides female age, dam breed influenced parturition difficulties. Looking at abnormal presentation only, repeat breeders had significantly more abnormal presentations than controls (Table 2). Although the percentage of calves weaned did not differ statistically between the controls (87.4) and repeat breeders (78.4), the trend favored the control females. Calving efficiency was higher ($P<.01$) in the control (80.2 pct) than the repeat-breeder group (65.8 pct). This increased calving efficiency in the control population was expected because of the definition of the repeat breeder, since repeat breeders missed one or more calvings before becoming part of the experimental population. Several factors like size, breed, and age of female, sire of calf, size of pelvic area, sex of calf, or hormonal asynchrony may have contributed to increased parturition difficulties in the repeat-breeder population.

The examination of the reproductive tracts indicated that repeat breeders (10.9 pct) had more anatomical defects than controls (0.0 pct). Although 3.6 percent of the repeat-breeder females failed to ovulate, this percentage was not different from control females (2.9 pct). Embryo and fetal development was lower ($P<.05$) in repeat breeders than controls (Table 3), and no recovery of either an oocyte or embryo was higher ($P<.05$) in the repeat breeders than controls. No differences were observed in degenerate embryos or in unfertilized oocytes between the groups.

Only the number of .03937 to .11811 in diameter follicles differed between the repeat breeders (26.3) and controls (39.1). No differences were found in ovarian weights, corpus luteum weights, or in the number of .15748 to .27559 in and greater than .31496 in diameter follicles and corpora albicantia. Corpus luteum weights were influenced by pregnancy status with heavier corpora lutea in females with normal embryonic develop-

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ment (.16 oz) compared to females with degenerate embryos or unfertilized oocytes (.13 oz) or nonrecovery of either an oocyte or embryo (.14 oz). Corpora lutea on the right side (.16 oz) were heavier than the left side (.12 oz). Ovulation occurred 60 percent of the time on the right ovary.

Total protein (24.0 *vs* 25.9 mg), zinc (2.1 *vs* 2.2μ g), and calcium (16.8 *vs* 19.7 μg) content of uterine flushings did not differ between control and repeat-breeder females, but days postmating significantly ($P<.05$) modulated protein, zinc, and calcium content. Progesterone content of uterine flushings between control (252.8 pg) and repeat-breeder females (107.7 pg) was not different statistically because the sample variability was large.

Progesterone content of peripheral serum between the two groups was similar on day 3 but differed ($P<.05$) on day 6 with controls (2.78 ng/ml) having higher concentrations than repeat breeders (1.91 ng/ml). Values on day 9 did not differ between groups. Luteinizing hormone (LH) peak heights did not differ between the groups (C, 71.8 *vs* RB, 94.3 ng/ml). Although the interval from estrus to the LH peak was not statistically different between groups because of sample variability, the mean interval for the controls (13.2 h) was less than the repeat breeders (21.3 h). The ratio of estradiol-17β to progesterone did not differ statistically between groups. However, the controls tended to have lower progesterone and higher estradiol-17β values compared to the repeat breeders. This could be interpreted to mean that the repeat breeders may be more asynchronous in their hormone secretion.

Various attempts were made to increase progesterone by giving gonadotropin releasing hormone or human chorionic gonadotropin at estrus to enhance and/or hasten corpus luteum formation and progesterone secretion. Pregnancy rate was not increased, but progesterone concentrations were increased in the repeat-breeder heifers. The addition of aspirin to the feed, as well as giving exogenous progesterone, did not increase pregnancy rate in the repeat-breeder females. It appears that serum progesterone concentrations may vary, but pregnancy is not increased in repeat breeders by raising peripheral levels of progesterone.

Analyses of the chromosomes indicated that 19 of 133 (14.3 pct) repeat-breeder females had a gross chromosomal aberration. These anomalies were the presumptive 1/29 translocation (10 females) and sex chromosome anomalies (9 females). The 1/29 translocation is where chromosome 1 joins chromosome 29 to make a large metacentric chromosome. Females with the 1/29 translocation have 59 instead of 60 chromosomes.

These investigations indicated that repeat breeding occurs in a low incidence (1.0 to 1.7 pct) in the Research Center's herds and is the result of several factors. The causes are classified in Table 4. Calving difficulties may influence a female to become a repeat breeder or may be another indicator of hormonal dysfunction. Excluding females with anatomical and chromosomal aberrations, ovarian dysfunction appears to be the largest cause of repeat breeding; however, pituitary factors could not be totally eliminated.

Table 1.—Calf crop losses to weaning (spring and fall calving seasons combined) and number of repeat-breeder females

	1979-80[a]	1980-81	1981-82	1982-83
Number females exposed to mating or AI	7,374	7,132	6,803	7,001
Percentage loss due to:				
a) Not pregnant at palpation	13.5	14.1	14.1	15.7
b) Palpated pregnant but failed to calve	1.7	2.4	3.2	2.6
c) Calf loss before 72 h[b]	13.4	6.2	7.1	9.1
d) Calf loss after 72 h[b]	1.6	1.5	2.0	3.7
Total loss	30.2	24.2	26.4	31.1
Percentage of total loss due to not pregnant at palpation	44.7	58.3	53.4	50.5
Number repeat-breeder females[c]	72	101	115	118
Percentage repeat breeder of total females exposed	1.0	1.4	1.7	1.7

[a]Year females exposed—year calved.
[b]Time calves died after parturition.
[c]Repeat breeder was a female not pregnant after two consecutive breeding seasons of 45 to 60 days' duration. Palpation was conducted at least 60 days after the end of the breeding season. All females had the opportunity to have 2 to 5 estrous cycles/breeding season or at least 4 to 10 estrous cycles to become pregnant before being classified as a repeat breeder.

Table 2.—Number and percentage[a] of parturitions by calving difficulty scores

Group		Partu-ritions/ number cows	Calving difficulty scores[b]							
			1	2	3	4	5	6	7	8
Control[c]	1st	102/102	55	5	5	20	2	8	4	3
			(53.9)	(4.8)	(4.9)	(19.6)	(2.0)	(7.8)	(3.8)	(2.8)
	All	392/102	325	10	6.	24	2	8	7	10
			(82.9)	(2.6)	(1.5)	(6.1)	(0.5)	(2.0)	(1.8)	(2.6)
Repeat	1st	241/241	100	7	8	57	11	11	38	8
			(41.5)	(2.9)	(3.3)	(23.6)	(4.6)	(4.6)	(16.2)	(3.3)
Breeder[c]	All	639/241	432	13	10	78	17	14	43	32
			(67.6)	(2.0)	(1.6)	(12.2)	(2.7)	(2.2)	(6.7)	(5.0)

[a]Numbers in parentheses are percentages.

[b]1 = calved unassisted, 2 = assistance given by hand, 3 = assistance with mechanical calf puller—little difficulty, 4 = assistance with mechanical calf puller—slight difficulty—no injury to cow or calf, 5 = assistance with mechanical calf puller—moderate difficulty—minor injury to cow or calf, 6 = assistance with mechanical calf puller—major difficulty—severe hiplock, usually more than 30-min delivery, 7 = caesarean birth, 8 = abnormal presentation or posture.

[c]Data for parous females only. All control females were parous while the repeat breeders were both parous (241) and nonparous (165).

Table 3.—Pregnancy status in control and repeat-breeder females at slaughter

Group	No. females	Pregnancy status (pct)			
		Normal embryo	Degenerate embryo	Unfertilized oocyte	No recovery
Control	99	76.8	9.1	6.0	8.1
Repeat Breeder	336	42.3	8.9	8.0	40.8

Table 4.—Causes and frequency of cause for repeat breeding in beef cattle

Cause	Frequency (pct)
Reproductive tract anatomical aberration	10.9
Anovulation	3.6
Chromosomal abnormalities	14.3
Nonrecovery of either an oocyte or embryo	34.7
Endocrine dysfunction and other causes	36.5

Embryo Transfer in Beef Cattle Research

Ralph R. Maurer and Acacia A. Alcivar[1]

Introduction

Embryo transfer techniques have been utilized to increase the number of desirable animals (e.g., exotic breeds) or to study factors influencing embryonic development. Embryo transfer is predominantly used at the Research Center as a research tool to answer questions about embryonic development and maternal influence on subsequent growth of the newborn calf.

Embryo transfer utilizes the techniques of 1)superovulation; 2)surgical or nonsurgical embryo collection and transfer; and 3)handling the embryo between collection and transfer. Therefore follicular development as well as fertilization rates play important roles in the production of viable embryos. A large variation in response to the superovulatory procedure exists among females in ovulation rate and number of transferable embryos. Approximately one-third of the female cattle induced to superovulate do not respond with transferable embryos. Only 40 to 60 percent of the embryos transferred develop into calves. Therefore we conducted several studies to investigate superovulatory and embryo transfer procedures. In addition, embryo transfer technology was employed to study maternal influences on postnatal (after birth) growth in calves.

Procedure

Superovulatory responses in follicle stimulation hormone (FSH)- or Pergonal®- treated heifers. Forty Angus x Hereford heifers averaging 389 days of age were observed for normal estrous (heat) behavior. Eight females were culled for irregular estrous cycles or inability to adapt to the confined conditions. The remaining females were divided into two groups of 16 and received either follicle stimulating hormone or Pergonal® (a purified gonadotropin extracted from urine of postmenopausal women) to induce superovulation on days 9 to 12 of the estrous cycle. Within each group one-half received prostaglandin ($PGF_{2\alpha}$) either intramuscularly or intravenously to induce regression of the corpus luteum. FSH was injected at a dosage of 4(a.m.), 4(p.m.); 3,3; 3,3; 2,2; and 1,1 mg every day for 5 days (total dose, 26 mg per heifer) while Pergonal® was injected at a dosage of 2(a.m.), 2(p.m.); 2,2; 1,1; 1,1; and 1,1 ampules (1 ampule = 75 IU FSH activity and 75 IU luteinizing hormone activity) every day for 5 days (total dose, 1050 IU per heifer). Prostaglandin was given 60 (25 mg) and 72 h (15 mg) after the initial superovulatory treatment began. Eleven heifers were artificially inseminated with frozen semen at 48, 60, and 72 h after the initial $PGF_{2\alpha}$ injection. Frequent blood samples were collected from all donor females throughout the superovulatory procedure for subsequent measurement of reproductive hormones.

Embryos were flushed nonsurgically via a three-way Foley catheter placed in each uterine horn. Phosphate-buffered saline was used as the flushing medium. The recovered embryos were classified as unfertilized oocytes, less than morula, morula, and blastocysts. Number of corpora lutea on each ovary was determined by rectal palpation.

Embryos were transferred in either modified phosphate-buffered saline (MPBS) plus 20 percent fetal calf serum or MPBS plus 1.5 percent bovine serum albumin. Placement in the recipient uterine horn was accomplished using either the Cassou gun or with a stainless steel tube and polyethylene tubing (4 ft length, outside diameter .066 in, inside diameter .046 in) attached to a one milliliter tuberculin syringe via a blunted 18 gauge needle.

A blood sample was collected from each recipient at the time of embryo transfer for determination of progesterone concentration.

Embryo development after prostaglandin E_2 (PGE_2) addition to the semen and progesterone, solcoseryl®, or PGE_2 to the transfer medium. Thirty-two Simmental crossbred heifers 14 to 16 months of age and seven Hereford cows were superovulated using a regime of 4,4; 3,3; 2,2; and 2,2 mg FSH 2x daily for four days. At 60, 72, and 84 h after the initial FSH injection, 9 mg $PGF_{2\alpha}$ (Lutalyse®) was injected to induce corpus luteum regression. All females were artificially inseminated with frozen semen at 48, 60, and 72 h after the initial $PGF_{2\alpha}$ injection. In addition 20 females (16 heifers and 4 cows) received 500 μ g PGE_2 in the semen extender at the first and second inseminations. The remaining 16 heifers and 3 cows received only the extended semen at all inseminations. Ovaries were palpated for corpora lutea numbers, and embryos were collected nonsurgically on day 8. Transferable embryos were placed in modified Dulbecco's phosphate-buffered medium containing either: no additive (control), 76.5 ng/ml progesterone, 0.1 percent dialyzed solcoseryl® (deproteinized dialysate of calf's blood), or 100 μ g/ml PGE_2.

Embryos were transferred nonsurgically using a Cassou embryo transfer gun in 100 to 200 μ l of medium to recipient cows aged 3 to 9 years. All recipient females were in estrus ± 48 h of the initial insemination time of the donor females. Recipient females not detected in estrus after receiving an embryo were slaughtered at 60 to 90 days after transfer to determine the reproductive status.

Reciprocal transfer of embryos to Brown Swiss and Hereford recipients. Brown Swiss and Hereford donors were superovulated with 5,5; 4,4; 3,3; 2,2 and 1,1 mg FSH 2x daily for 5 days. $PGF_{2\alpha}$ was injected at 60 (25 mg) and 72 (15 mg) h after the initial FSH injection. At 48, 60, and 72 h after the initial $PGF_{2\alpha}$ injection, Brown Swiss donors were artificially inseminated with semen from Hereford sires and Hereford donors with semen from Brown Swiss sires. Embryos were collected nonsurgically and corpora lutea were counted on day 8 of gestation. Embryos were transferred nonsurgically to recipients which were in estrus ± 48 h of the time the donors were in estrus. Embryos from each breed of donor were transferred to Brown Swiss and Hereford recipients as depicted in the experimental design shown in Table 1. At birth, one-half of the males and females produced by each recipient breed was weaned after three days of age and placed on milk replacer and dry feed. The remaining offspring were allowed to nurse their recipient dams for 160 to 200 days before they were weaned. All males were castrated shortly after birth. Steers were slaughtered upon attaining a liveweight of 1,150 lb and heifers were slaughtered upon reaching a liveweight of 1,050 lb.

Results

Superovulatory responses in follicle stimulating hormone (FSH)- or Pergonal®-treated heifers. Estrus was detected in 95 percent of the heifers treated with FSH or Pergonal®. The interval between $PGF_{2\alpha}$ injection to estrus was longer for FSH-treated females (59.2 ± 2.2 h) compared to Pergonal®-treated heifers (50.4 ± 2.4 h). No differences were found between routes of $PGF_{2\alpha}$ administration in the interval between $PGF_{2\alpha}$

[1]Maurer is a research physiologist, Reproduction Unit, MARC; and Alcivar is a graduate student at Iowa State University (formerly a masters student, Reproduction Unit, MARC).

Table 1.—Experimental design for transferring Brown Swiss X Hereford or Hereford X Brown Swiss embryos to Hereford or Brown Swiss recipients

Breed Sire	Breed donor female	Reciprocal embryos	Recipient female breed	Postnatal rearing
Brown Swiss (B) x Hereford (H)		BH	Brown Swiss	Nursed
				Pail fed
		BH	Hereford	Nursed
				Pail fed
Hereford (H) x Brown Swiss (B)		HB	Brown Swiss	Nursed
				Pail fed
		HB	Hereford	Nursed
				Pail fed

Table 2.—Number of corpora lutea, oocytes, or embryos recovered and usable morula and blastocysts

Gonadotropin $PGF_{2\alpha}$ Administration[a]	FSH		Pergonal	
	IM	IV	IM	IV
No. of heifers	8	8	8	8
No. of corpora lutea	12.9 ± 2.0	10.4 ± 2.1	8.5 ± 1.3	11.5 ± 1.9
No. of oocytes/embryos recovered	9.5 ± 2.7	8.4 ± 2.5	5.8 ± 1.3	9.1 ± 2.2
Percent recovered	74	80	68	79
No. usable morula and blastocysts	4.8 ± 1.4	5.0 ± 1.3	4.25 ± 1.3	6.0 ± 2.2
Percent transferable	51	60	73	66

[a]IM = intramuscular injection. IV = intravenous injection.

and estrus (52.8 ± 2.6 h for intramuscular and 56.8 ± 2.5 h for intravenous). No differences were found between the FSH and Pergonal® or between $PGF_{2\alpha}$ administration in the number of corpora lutea, oocytes, or embryos recovered, and transferable embryos (Table 2).

A total of 262 oocytes and embryos were collected nonsurgically and distributed over treatments as listed in Table 3. The Pergonal®-treated females showed more advanced development in their embryos which was a reflection in the shorter interval from the $PGF_{2\alpha}$ injection to estrus. Therefore, production of transferable embryos was not influenced by superovulatory regime nor by route of $PGF_{2\alpha}$ administration.

The interval between $PGF_{2\alpha}$ injection and the luteinizing hormone (LH) peak was shorter for the Pergonal®- than FSH-treated heifers (Table 4). LH peak heights or areas did not differ between groups. However, the estradiol-17β was higher in the Pergonal® than FSH-treated females. Premature regression of the corpora lutea was determined in 19 percent of the heifers as indicated by the decreased progesterone concentrations at embryo collection. Only 17 percent of the embryos collected from these females were of transferable quality. Only 2 of 16 embryos transferred from heifers with regressing CL's developed into a fetus upon transfer to recipients.

Embryos from FSH-treated heifers (29 pct) resulted in more pregnancies ($P<.10$) than embryos from Pergonal-treated heifers (13 pct; Table 5). Pregnancy rates of technicians did differ ($P<.05$). Neither the medium used to transfer the embryos nor the type of transfer instrument affected the pregnancy rate. Concentration of serum progesterone in recipients the day of transfer was lower ($P<.05$) in the 19 recipients which maintained pregnancy than in females which did not maintain pregnancy (2.6 ± 0.4 *vs* 3.2 ± 0.2 ng/ml, respectively).

Table 3.—Distribution of embryos collected at day 8 according to developmental stages and superovulatory regime[a]

Embryo developmental stages	Superovulatory regime		Total
	FSH	Pergonal[b]	
Unfertilized	15 (11)	9 (8)	24 (9)
Less than morula	36 (25)	23 (19)	29 (23)
Morula	40 (28)	12 (10)	52 (20)
Blastocysts	52 (36)	75 (63)	127 (48)
Total	143	119	262

[a]Numbers in parentheses are percentages.
[b]Includes embryos from heifers which were difficult to inseminate.

Table 4.—Intervals from $PGF_{2\alpha}$ administration to luteinizing hormone (LH) peak height and to estrus[a]

Treatment	$PGF_{2\alpha}$ Administration	
	To LH peak height (h)	To estrus (h)
FSH-IM	47	59
FSH-IV	61	60
Pergonal®-IM	42	46
Pergonal®-IV	52	54

[a]Values are means. IM = intramuscular injection. IV = intravenous injection.

Table 5.—Pregnancy rates of embryos collected from FSH- and Pergonal®-treated donors and transferred by different technicians

Transferrer	Embryos from donors treated with:		
	FSH	Pergonal®	Total
Technician I	11/22 (50)	4/24 (17)	15/46 (33)
Technician II	2/22 (9)	2/25 (8)	4/47 (9)[b]
Total	13/44 (29)	6/49 (12)[a]	19/93 (20)

[a]Significant difference ($P<.05$).
[b]Significant difference ($P<.01$).

Table 6.—Superovulatory response in females with or without PGE_2 addition to the semen at the time of insemination

	Control[a]	PGE_2[a]	Statistical Difference[b]
Number of donors[c]	13 (6)	11 (9)	NS
Number of corpora lutea	6.6 ± 1.0	8.6 ± 1.2	NS
Number of unfertilized	0.2 ± 0.5	1.4 ± 0.7	NS
Number less than morula	0.5 ± 0.3	0.2 ± 0.3	NS
Number morula	0.5 ± 0.2	0.6 ± 0.2	NS
Number blastocysts	3.2 ± 1.3	4.5 ± 1.6	NS
Percent transferable	66.7 + 17.3	52.3 ± 21.5	NS

[a]Least-squares means ± standard error.
[b]NS = non-significant difference.
[c]Numbers in parentheses are the number of females in which no embryos or oocytes were found.

Embryo development after prostaglandin E_2 (PGE_2) addition to the semen and progesterone, solcoseryl®, or PGE_2 to the transfer medium. The addition of PGE_2 to the semen did not affect ovulation rate or embryo quality in donor females (Table 6). However, more ($P<.10$) embryos from the females given PGE_2 (38 pct) at insemination developed into a fetus than did control embryos (24 pct; Table 7).

The addition of progesterone and, to a less extent, PGE_2 to the transfer medium did improve pregnancy rates. An interaction between donor treatment and embryo treatment was found with more embryos in the progesterone medium developing from control donors than PGE_2 donors, while in the other three treatments more embryos from PGE_2 donors developed into fetuses than from control donors. Recipient age, donor recipient synchrony, and sires did not influence embryonic development. Embryo quality influenced pregnancy rate as more embryos ($P<.05$) classified as good developed into a fetus than did either embryos classified as fair or poor (Table 8). Therefore, embryo selection and classification, transfer medium, and superovulatory regime may influence subsequent pregnancy rates in recipients.

Reciprocal transfer of embryos to Brown Swiss and Hereford recipients. Males were heavier ($P<.05$) at birth than females (Table 9). However the uterine environment (recipient breed) nor ovum cytoplasma (donor breed) influenced the birth weight of the calves. Steers gained faster ($P<.05$) than heifers and reached slaughter weight sooner ($P<.10$) than heifers. Donor breed did not influence prenatal (before birth) or postnatal (after birth) gains. Recipient breeds influenced average daily gain to weaning with calves born to Brown Swiss recipients being heavier ($P<.01$) than calves born to Hereford recipients. Postweaning gains were not influenced by recipient breed. However, hot carcass weights were heavier ($P<.01$) in animals born to Brown Swiss recipients than in animals from Hereford recipients. This indicates that the uterine environment may influence subsequent postnatal development at least shortly after birth. However, further research is needed to determine how permanent and how significant these maternal changes are in cattle.

Table 7.—Pregnancy rates by donor and embryo treatment[a]

	Embryo Treatment				
Donor Treatment	Control	Progesterone	Solcoseryl	PGE_2	Total
Control	0/8 (0)	6/8 (75)	1/9 (11)	1/9 (11)	8/34 (24)
PGE_2	2/10 (20)	3/10 (30)	4/10 (40)	6/10 (60)	15/40 (38)
Total	2/18 (11)	9/18 (50)	5/19 (26)	7/19 (37)	

[a]Numbers in parentheses are percentages of embryos developing into fetuses.

Table 8.—Pregnancy rate by embryo quality

Embryo Quality	No. Embryos Transferred	No. Pregnant	Percent Pregnant
Good	35	15	43
Fair	24	5	21
Fair to poor	15	3	20

Table 9.—Birth, adjusted weaning and postweaning weights, and age to slaughter in Brown Swiss x Hereford reciprocal embryos transferred to Brown Swiss x Hereford recipients

Main effects		No. observations	Birth wt (lb)	Adj. 200 day wt (lb)	ADG[a] prewean. (lb)	ADG[a] postwean. (lb)	ADG[a] (lb)	Slaughter age (day)
Ovum[b]	HB	12	92.1 ± 4.2	522.0 ± 15.6	2.12 ± .07	2.25 ± .11	2.18 ± .07	466 ± 17
	BH	13	92.1 ± 3.3	519.1 ± 13.8	2.12 ± .04	2.09 ± .09	2.09 ± .07	482 ± 15
Recipient breed	B	9	92.7 ± 4.8	557.3 ± 18.0	2.29 ± .07	2.16 ± .11	2.23 ± .09	469 ± 19
	H	16	91.5 ± 3.0	483.8 ± 11.3	1.94 ± .04	2.20 ± .07	2.07 ± .04	479 ± 12
Postnatal[c]	N	13	92.7 ± 3.6	543.9 ± 13.6	2.23 ± .04	2.20 ± .09	2.20 ± .07	465 ± 15
	W	12	91.4 ± 4.1	497.1 ± 15.3	2.01 ± .07	2.16 ± .09	2.07 ± .07	482 ± 16
Sex[d]	M	14	98.5 ± 3.3	558.8 ± 12.3	2.27 ± .26	2.40 ± .09	2.34 ± .04	450 ± 13
	F	11	85.6 ± 4.7	482.3 ± 17.4	1.96 ± .07	1.95 ± .11	1.96 ± .09	498 ± 19

[a]ADG = ave. daily gain.
[b]HB = Hereford (H) sire X Brown Swiss (B) dam; BH = Brown Swiss sire X Hereford dam.
[c]N = nursed, W = weaned at 3 days.
[d]M = male; F = female

Target Tissue Effects of Active Immunization of Heifers Against Steroids

Thomas H. Wise, Calvin L. Ferrell, and Bruce D. Schanbacher[1]

Introduction

Gonadal steroids mediate many responses throughout the body, many of which may have economic considerations. Antibodies made against steroids by active immunization have provided unique tools to begin to identify steroid target tissues and understand some of the body responses to gonadal steroids. Immunization of farm animals against steroids may potentiate their effects upon target tissues resulting in increased ovulation rate (androgens) and increased feed efficiency and rate of gain (estrogens).

A major secretion function of the ovary involves the release of sex steroids which have multiple effects upon the body. Follicles release estrogen, which prepares the animal for breeding. After ovulation, the follicle develops into a corpus luteum that secretes progesterone and enables the pregnancy to be maintained. Beyond these general concepts, our knowledge of sex steroidal effects upon the body are limited. Only recently have ovarian androgens (primarily a male gonadal secretion) been identified as having a possible role in follicular maturation. Estrogenic effects upon growth are well acknowledged and utilized to the advantage of cattle feeders, but actual mechanisms involved are unknown. The purpose of these studies were to (1) identify the reproductive effects of active immunization against androstenedione and (2) evaluate the mechanisms of antibody-steroid effects with active immunization against estradiol in feedlot heifers.

Procedure

Androstenedione and estradiol were linked to Keyhole limpet hemocyanin (KLH) or bovine serum albumin (BSA) to provide a stimulatory immune response in cycling beef heifers. In the first experiment, cycling heifers were actively immunized against the carrier protein (KLH) and the androstenedione antigen (Table 1). In the second experiment (II), animals were immunized against two different antigenic proteins linked to estradiol (BSA and KLH). Reproductive efficiency was monitored in the first experiment and rate of gain and feed conversion efficiency monitored in the second. Animals in experiment II were fed *ad libitum* for 170 days.

Results

Animals immunized against androstenedione had an increased ovulation rate (1.3/cow) resulting in 100 percent overall pregnancy rate in treated animals and 80 percent in control animals (Table 1). The increased ovulation rate in animals immunized against androstenedione implies that ovarian androgens are important in the recruitment and maturation of ovulatory follicles.

In experiment II, animals immunized against estrogen showed a classical increase in rate of gain and feed efficiency (Table 2) from the estrogenic effects upon target tissues. The animal's own estrogen was utilized to potentiate growth and feed conversion when immunized against estrogens. The two antigenic proteins utilized (KLH and BSA) revealed different responses at the ovarian level. Animals immunized against BSA conjugate were only 50 percent cyclic and had a large number of cystic follicles, whereas animals immunized against the KLH conjugate were normal in reproductive function (Table 2).

[1]Wise and Schanbacher are research physiologists, Reproduction Unit, and Ferrell is a research animal scientist, Nutrition Unit, MARC.

Table 1.—Comparison of fecundity and fertility of animals immunized against Keyhole limpet hemocyanin and Keyhole limpet hemocyanin conjugated to androstenedione

	Control-saline	Control-anti-KLH	Anti-androstenedione
Percent serum androstenedione binding (1:100)	< 1	< 1	21
Ovulation rate	1.0 (10/10)	1.1 (11/10)	1.3[a] (18/14)
Pregnancy rate, pct	80 (8/10)	70 (7/10)	79 (11/14)
Calves/cow	0.8 (8/10)	0.8 (8/10)	1.0 (14/14)

[a]$p < 0.06$.

Table 2.—Comparison of average daily gain and feed efficiency of animals actively immunized against estradiol conjugated to Keyhole limpet hemocyanin (Anti-KLH-estradiol) and bovine serum albumin (Anti-BSA-estradiol).

	Control-saline	Anti-KLH-estradiol	Anti-BSA-estradiol
Percent serum estradiol binding (1:100)	0.39	31.0	43.5
Ovulation rate	0.8 (15/18)	.9 (17/18)	0.5[a] (9/18)
Daily gain (lb)	1.83	2.09[a]	2.13[a]
Gain/Feed consumption (lb/lb)	0.118	0.126	0.142[a]

[a]$p < 0.05$.

Effects of Sex Condition and Diet on Growth and Carcass Characteristics

John D. Crouse, Calvin L. Ferrell, and Larry V. Cundiff[1]

Introduction

Studies quantifying the differences between bulls and steers have generally shown that bulls gain more rapidly and more efficiently than steers and produce leaner carcasses. The average of these studies gave bulls a 17 percent advantage in average daily gain and a 13 percent advantage in converting feed to liveweight gain. Feed efficiencies reported in these studies were determined on animals fed to similar ages or weights. The effects of sex condition on feed efficiency of animals fed to a similar fat composition or marbling endpoint needs to be examined.

It has also been reported that average dressing percentages for bulls and steers were similar. However, bulls possessed an average advantage of 2.6 percentage points of estimated boneless chuck, rib, loin, and round over steers. The percentage of fat in ribs from bulls fed high-energy diets was only slightly greater than for bulls fed low-energy diets. The opposite has been observed in steers. These observations indicate that the detrimental effects of castration on growth rate and feed efficiency have been greater on a higher plane of nutrition than on a lower plane of nutrition. The interaction of sex condition by dietary energy density needs further clarification.

The objectives of the present study were to determine the effects of male sex condition, breed type, and dietary energy density on youthful beef production performance and carcass merit at a constant percentage of rib fat.

Procedure

Material. Cattle were castrated (75 head) or kept intact (87 head). Castration was performed within 24 h after birth on alternate calves by date and time of birth. Calves were born in March or April, weaned in November, and placed on trial the first week of December. (Calves were on pasture with their dams until weaning.)

Feeding. At weaning, animals within sex condition and breed groups were randomly assigned to either the feeding trial (138 head) or an initial slaughter group (24 head). The sex condition x breed groups were then randomly assigned to the low- (2.52 Mcal/kg) or high-energy (3.03 Mcal/kg) density corn silage diets. Cattle were adjusted to the high-energy diet over a 28-day period. Uneaten feed was weighed weekly and when cattle were weighed at 28-day intervals or before slaughter.

Slaughter and Carcass Evaluation. Three cattle within each sex condition, breed, and diet treatment group were slaughtered at the initiation of the feeding trial at 8 months of age. Two animals within each pen were subsequently randomly selected at 12 or 16 months of age for slaughter. Original plans were to have the final slaughter at 20 months of age; however, the study was terminated at 17 months of age, and remaining animals were slaughtered because animals were fattening rapidly and some were becoming very large.

After a 24-h chill in a 33°F cooler, carcasses were evaluated for USDA (1976) grade factors by an individual trained as a USDA grader. The exposed 12th rib longissimus muscle lean was also evaluated for heat ring (degree of two-tone color of lean, and lean and subcutaneous fat separation) and lean color. Scoring schemes for traits are given in Table 3.

The 9-10-11th rib section of the left side of the carcass was removed by procedures outlined by Hankins and Howe (1946). The soft tissue was separated and ground thoroughly, mixed, and subsampled in triplicate for chemical analyses. Moisture and fat were determined by oven drying 2 g at 212°F for 12 h and soxhlet ether extraction of the dried sample for 48 h (AOAC, 1980).

Results

Growth and Performance. No sex condition x diet interaction was observed. This indicates that performance differences between sexes were not dependent on dietary energy (Table 1). Regression coefficients show that intact male cattle increased in weight at a greater rate over the duration of the feeding trial as compared to castrates.

Energy intake (Mcal ME/day) was greater on the high-energy diet for intact males than castrates, while energy intake was similar between the two sexes on the low-energy diet (Table 2).

The Effects of Sex Condition. Intact males were heavier than castrates over a constant age interval (Table 3). These observations support earlier reports that bulls gain faster than steers. Intact males tended to have improved feed conversions over a constant-age interval. The 15 percent difference in DM/unit of gain between the sex conditions is similar to previously reported values for intact males *vs* steers fed over a constant time interval. Advantages in feed efficiencies of intact males were completely removed, however, when efficiency data were statistically adjusted to live-animal weights associated with a constant percentage of fat in the rib (33.5 pct).

Improved feed conversions of intact males were due to greater rates of gain because intact males consumed greater quantities of energy (Table 2). Differences in daily energy intake between intact males and castrates were even greater when data were adjusted to a constant percentage of rib fat and would account for the decreased efficiency of intact males fed to constant composition endpoints when compared to castrates.

The Effects of Diet. The high-energy diet produced faster ($P<.01$) gains than the low-energy diet at an age-constant interval (Table 3). However, weights of animals were heavier for the low-energy diet group when data were adjusted to a constant percentage of rib fat. These results indicate that gains produced on the low-energy diet were of a leaner composition than gains on the high-energy diet. Results of previous studies have also indicated that high-energy density diets increase rate of gain mainly through increased fat deposition.

Carcass Characteristics

Sex Effects. Interactions were not an important source of variation for carcass traits. Carcass data are presented in Table 4 and were adjusted to constant percentage of rib fat.

At equal rib fat, intact males were heavier, had larger 12th rib longissimus muscle areas, and had thicker fat thicknesses than castrates. Marbling scores for intact males tended to be lower than for castrates. These data indicate that intact males are larger and more muscular than castrates at a given percentage of rib fat.

Carcasses from intact males were physiologically more mature than carcasses from castrates as indicated by skeletal and lean maturity scores (Table 4). Lean of carcasses from intact males was also softer and coarser in texture and exhibited a greater degree of heat ring than lean of carcasses obtained from castrates. In general, at a constant percentage of rib fat, meat from intact males was lower in quality than that from castrates.

Diet Effects. Diet had little effect on carcass characteristics. Color of lean meat from cattle fed the low-energy diet was darker than lean meat from cattle fed the high-energy diet

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(Table 4). Other carcass characteristics were very similar between dietary treatments. It was anticipated that carcasses from the low-energy dietary treatment would be heavier and have larger longissimus muscle areas than carcasses from the high-energy density diet. It has been observed that high-energy density diets increase fat deposition relative to protein deposition.

Table 1.—Means and animal age regressions for live-animal weights[a]

	Breed group		Age regression coefficient
	Angus	Simmental	
	(lb)	(lb)	
Bulls	910	1,111	.57
Steers	873	1,008	.47
Low energy	860	1,012	.49
High energy	924	1,107	.57

[a]Interactions were observed for Sex Condition (SC) X Slaughter Age (SA) and Diet (D) x Slaughter Age (SA).

Table 2.—Means for energy intake (Mcal ME/day) for sex condition x diet subclass means[a]

	Diet	
	Low	High
Bulls	22.5	30.0
Steers	21.3	26.2

[a]Interactions were observed for sex condition x diet and breed group x diet.

Table 3.—Means of growth and performance traits

	Traits							
	Live animal weight		Energy intake		Dry matter/gain		Mcal ME/gain	
	Age constant	Composition constant[a]	Age constant	Composition constant[a]	Age constant	Composition constant[a]	Age constant	Composition constant[a]
	lb		Mcal ME/day		Ratio		Ratio	
Sex condition:								
Bulls	1,012	1,323	26.2[b]	32.5	8.5	11.2	25.8	34.1
Steers	941	1,003	23.7[c]	24.7	10.0	10.7	30.2	32.4
Diet:								
Low	935	1,190	21.8[b]	22.3	9.3	11.7	28.2	35.3
High	1,016	1,133	28.2[c]	30.0	9.2	8.6	27.8	31.6

[a]Means estimated by linear regression.
[bc]Means within treatment differ ($P<.01$).

Table 4.—Means of carcass traits at a constant percentage of fat of the rib

Trait	Sex condition		Diet	
	Bulls	Steers	Low	High
Carcass wt, lb	824	621	730	717
Heat ring[a]	2.36	1.96	2.28	2.04
Lean color[b]	5.39	4.26	5.26	4.39
Lean maturity[c]	1.68	1.44	1.60	1.53
Skeletal maturity[c]	1.81	1.32	1.59	1.54
Overall maturity[c]	1.79	1.38	1.61	1.57
Marbling[d]	Sl^{14}	Sl^{50}	Sl^{46}	Sl^{19}
Longissimus area, in^2	14.0	11.4	12.9	12.6
KPH	2.43	2.45	2.31	2.57
Firmness[e]	4.14	4.71	4.20	4.65
Texture[f]	4.25	4.80	4.37	4.68
Fat thickness, in	.4	.3	.3	.3
Adj. fat thickness, in	.4	.3	.3	.3

[a]Heat ring scored: 1 = no heat ring to 5 = severe two-tone effect with a soft, sunken longissimus muscle.
[b]Lean color scored: 1 = extremely light to 8 = extremely dark.
[c]Maturity scored: 1 = A to 2 = B.
[d]Marbling scored: Sl = slight. Higher superscripts indicate greater amounts of marbling within the slight category.
[e]Firmness scored: 1 = very soft to 7 = very firm.
[f]Texture scored: 1 = very coarse to 7 = very fine.

Effects of Sex Condition, Diet, and Electrical Stimulation on the Collagen and Palatability of Two Muscles

John D. Crouse, H. Russell Cross, and Steven C. Seideman[1]

Introduction

Meat obtained from intact males has been observed to be less tender than meat obtained from castrated males. Studies have shown that meat from intact males was one sensory panel score less tender than comparable meat from castrated males when animals were fed to about the same age. Reported studies comparing palatability characteristics of meat from bulls and steers have been made on animals fed to similar ages or weights; consequently, compared sex conditions have been confounded with carcass compositional differences.

The objectives of the present study were to determine the effects of sex condition and dietary energy density on meat palatability when cattle were fed to the same compositional endpoint.

Procedure

Design and Cattle. Steaks were obtained from carcasses of intact (87 head) or castrated (75 head) cattle that were fed either a low (86 head) or high (76 head) energy density diet. Animals were slaughtered at 8, 12, 16, or 17 months of age.

Animals were slaughtered at the MARC abattoir. Carcasses were split and, within a 45-min period, the right side of each carcass was electrically stimulated (ES).

Carcass Evaluation. After a 24-h chill in a 33°F cooler, carcasses were evaluated for USDA (1976) grade factors by an individual trained as a USDA grader. Growth and carcass data were summarized in a companion paper ("Effects of Sex Condition and Diet on Growth and Carcass Characteristics").

Upon completion of carcass evaluation, the 9-10-11th rib section was removed for chemical analysis of the soft tissue. After seven days of aging at 33°F the longissimus muscle (LD; ribeye) located in the region of the second through fourth lumbar vertebra of the left and right sides, was removed and trimmed of fat in excess of .5 in. In addition, the semimembranosus (SM; top round) muscle from the left side was removed for shear force determinations.

Sensory Panel. A descriptive attribute panel was trained and tested. Panelists evaluated samples in individual booths. Panelists evaluated each sample for variation in juiciness (1 = extremely dry; 8 = extremely juicy), ease of fragmentation (1 = extremely difficult; 8 = extremely easy), amount of connective tissue (1 = abundant; 8 = none), overall tenderness (1 = extremely tough; 8 = extremely tender), flavor intensity (1 = extremely bland; 8 = extremely intense), and off-flavor (1 = intense; 4 = none).

Results

Cookery and Sensory Characteristics:

Effects of Sex Condition. Cooking loss and cooking time were similar between sex conditions (Table 1). Meat from intact males was less tender than from castrated males at a constant percentage rib fatness. Differences in tenderness were reflected in increased sensory panel-perceived quantities of connective tissue in meat from intact males. Meat from intact males was also more difficult for sensory panelists to fragment.

Sensory panelists detected greater off flavors in meat from intact males as compared to meat from castrates. However, this difference was small in magnitude (.16 of a score), and the practical importance of the difference is questionable.

Effects of Diet. Cooking losses and cooking time of meat samples were similar between dietary treatments (Table 1). Unexpectedly, meat from the low-energy diet was more tender and possessed less connective tissue than meat from the high-energy diet. Meat from the low-energy diet also was observed to be easier to fragment than meat from the high-energy diet. Improved tenderness in the present study was likely associated with decreased quantities of collagen in meat from cattle fed the low-energy diet. Evidently, high-energy diets enhanced collagen development in this study.

Muscles. Differences between muscles for shear force was consistent between sex conditions, breed groups, and dietary treatments. The overall mean difference between muscles (LD-SM = .3 lb) was not statistically significant. These data indicate that SM roasts cooked by dry heat methods are equal in shear force values to LD steaks cooked by broiling.

Collagen:

Effects of Sex Condition. Collagen characteristics were similar for each sex, regardless of diet fed. Although not statistically significant, intact males tended to possess lean with greater quantities of collagen, greater quantities of insoluble collagen, and lower quantities of percentage soluble collagen (Table 2) when cattle were fed to similar rib-composition endpoints. Animals that had greater quantities of fat also had relatively less soluble collagen. These factors may offset one another in meat sensory characteristics.

Effects of Diet. Lean obtained from cattle produced on the high-energy diet tended ($P>.05$) to have greater quantities of total collagen and similar quantities of insoluble collagen. Relatively less ($P<.05$) collagen was soluble in the lean from cattle fed the low-energy diet.

Relationships Among Collagen and Sensory Traits. Correlations among collagen and sensory traits are given in Table 3. Total collagen was highly correlated with insoluble (mg) and soluble (mg) collagen, but only moderately correlated with percentage of soluble collagen. These associations were not dependent upon subclass means and indicate that relative quantities of soluble collagen are largely associated with factors other than sex condition, diet, or percentage of fat in the rib. Insoluble and soluble collagen were also moderately correlated.

Low correlations were observed for collagen with tenderness or shear force value. The correlation of total collagen with sensory panelists' perceptions of connective tissue was very low. These data indicate that total collagen content of the lean was not highly associated with subjective or objective measures of meat textural properties. Similar relationships were observed for insoluble collagen and sensory traits.

Correlations among sensory scores for ease of fragmentation, connective tissue, and tenderness were very high. Meat that had greater ease of fragmentation and smaller amounts of connective tissue was associated with tenderness. Ease of fragmentation and amount of connective tissue are very highly associated. In concept, ease of fragmentation and amount of connective tissue observation systems are designed to determine if the lack of tenderness is due to the myofibrillar or the connective tissue portion of the lean. However, in reality, meat that is hard to fragment also results in a high amount of residue after chewing (basis for amount of connective tissue ratings). Therefore, it appears that the use of ease of fragmentation observations and amount of connective tissue observations may measure the same characteristic.

[1]Crouse is the research leader, Meats Unit, MARC; Cross is a professor of animal science, Texas A&M University (formerly the research leader, Meats Unit, MARC); and Seideman is a research food technologist, Meats Unit, MARC.

Table 1.—Means of cooking and sensory traits over a constant percentage of rib fatness

	Treatment			
	Sex condition		Diet	
Trait	Bull	Steer	Low	High
Cooking loss, pct[a]	35.1	35.2	35.0	35.3
Cooking time, min	33.2	32.4	32.4	33.3
Juciness[b]	5.27	5.34	5.36	5.25
Fragmentation ease[c]	5.01	5.29	5.28	5.02
Connective tissue[d]	4.93	5.19	5.20	4.91
Tenderness[e]	5.09	5.32	5.35	5.06
Flavor intensity[f]	5.47	5.50	5.54	5.44
Off-flavor[g]	2.72	2.88	2.75	2.85
Shear force, lb[h]	10.3	8.9	9.4	9.8

[a]Cooking loss, percent = [(frozen weight) - cooked weight − (frozen weight)] × 100.
[b]Juiciness scored: 1 = extremely dry to 8 = extremely juicy.
[c]Ease of fragmentation scored: 1 = extremely difficult to 8 = extremely easy.
[d]Amount of connective tissue scored. 1 = abundant to 8 = none.
[e]Tenderness scored: 1 = extremely tough to 8 = extremely tender.
[f]Flavor intensity scored: 1 = extremely bland to 8 = extremely intense.
[g]Off-flavor scored: 1 = intense to 4 = none.
[h]Longissimus and SM muscles.

Table 2.—Means of collagen traits over a constant percentage of rib fatness

	Treatment			
	Sex condition		Diet	
Trait	Bull	Steer	Low	High
Total collagen[a]	4.76	4.25	4.30	4.71
Insoluble collagen[a]	3.86	3.42	3.61	3.68
Soluble collagen[a]	.89	.82	.69	1.03
Soluble collagen, pct[b]	18.8	19.2	16.2	21.8

[a]Expressed as mg/g. The longissimus muscle was observed.
[b]Expressed as a percentage of total collagen.

Table 3.—Correlations among collagen and sensory traits

Trait	1	2	3	4	5	6	7	8
1. Total collagen[a]	--	.97	.73	.24	.07	.05	.07	.04
2. Insoluble collagen[a]	--	--	.54	−.01	.16	.14	.17	−.03
3. Soluble collagen[a]	--	--	--	.83	−.20	−.22	−.25	.24
4. Soluble collagen, pct	--	--	--	--	−.31	−.32	−.38	−.35
5. Fragmentation	--	--	--	--	--	.97	.96	−.43
6. Connective tissue	--	--	--	--	--	--	.94	−.61
7. Tenderness	--	--	--	--	--	--	--	−.58
8. Shear force	--	--	--	--	--	--	--	--

[a]Expressed as mg/g for computations.

The Effects of Carcass Electrical Stimulation and Cooler Temperature on the Quality and Palatability of Bull and Steer Beef

John D. Crouse, Steven C. Seideman, and H. Russell Cross[1]

Introduction

The advantages of producing bulls as opposed to steers in production efficiency, performance, and carcass leanness have been well documented. However, it also has been observed that bulls have darker colored lean and lower carcass quality grades than steers. In all studies summarized in a literature review, meat obtained from bulls was less tender when compared with meat from steers. Consequently, the superiority of bulls over steers in performance and carcass cutability have been largely countered by the inferior carcass quality of bulls. Production of beef by bulls, therefore, has not been widely undertaken in the United States.

Recent technological advances in meat processing may enhance bull beef quality. A review indicates that electrical stimulation of prerigor carcasses will improve tenderness and enhance lean color and marbling of beef. Improvement in tenderness by electrical stimulation was greatest when control samples had higher shear force requirements.

High temperature, early postmortem carcass conditioning may also improve palatability characteristics of meat from bulls.

Improvement in visual appeal and palatability of bull beef would certainly be in the best interest of the beef industry. The objective of this study was to examine postmortem treatments that could lead to improved meat quality of beef obtained from bulls. Methods studied were carcass electrical stimulation and high temperature conditioning.

Procedures

Animals. Carcasses were obtained from Hereford bulls (44 head) and Hereford steers (27 head) that were born in March or April, weaned at 8 months of age, and fed a corn silage diet until 15 months of age. Animals were then fed, until slaughter, an 84 percent total digestible nutrient corn-corn silage diet supplemented with soybean meal and minerals. Bulls were fed in one pen as a group, and steers were fed in another pen as a group.

Slaughter. Steers were slaughtered when the average 12th rib fat thickness for all steers was .5 in (17 mo of age), as evaluated by visual appraisal. Bulls were slaughtered when the average 12th rib fat thickness for all bulls was .3 in (18 mo of age), as evaluated by visual appraisal. Bulls were selected with less fat thickness than steers because it was considered unreasonable to feed bulls to weights required to attain fat thicknesses equivalent to those of fed market weight steers. It was also considered that one of the competitive advantages of bulls for beef production was leanness.

Postmortem Treatments. Carcasses were split, each side weighed, and the right side electrically stimulated (ES) within 1 h postmortem. The ES consisted of 17 impulses at 550 volts (AC), 2 to 2.5 amps and 60 Hz for a 1.8-sec duration with a 1.8-sec pause between impulses. The left sides were used as controls (Cn). All carcasses were held at a cooler temperature of 60°F for 1 h post-stimulation. Thirty-six bull and steer carcasses were then moved to a 33°F cooler. Thirty-five bull and steer carcasses remained in the 60°F cooler for an additional 12 h postmortem, after which time they were placed in the 33°F cooler.

Carcass Evaluation. Intact longissimus (ribeye) muscle temperature and pH of each side were measured at stimulation and at 1, 2, 3, 6, 12, 18, and 48 h post-stimulation.

Carcasses were evaluated for quality and yield at 48 h postmortem. Lean color of the longissimus muscle at the 12th rib was scored from 1 = light cherry red through 8 = very dark red after at least a 30-min bloom period.

Sensory Panel. A descriptive attribute panel was used. Panelists evaluated each sample according to differences in juiciness (1 = extremely dry, 8 = extremely juicy), ease of fragmentation (1 = extremely difficult, 8 = extremely easy), amount of connective tissue (1 = abundant, 8 = none), overall tenderness (1 = extremely tough, 8 = extremely tender), and flavor intensity (1 = extremely bland, 8 = extremely intense).

Results

Sex Effects. Bulls had a slower rate of carcass temperature decline than steers. Differences between bulls and steers in carcass temperature diminished with time in the cooler resulting in a significant sex x time interaction. The two groups of carcasses reached equilibrium after being in the cooler for a 48-h period, as would have been expected over this time period. Evidently, heavier carcass weights and thicker longissimus muscles of bulls resulted in a slower chill rate than that of steers.

The longissimus muscles of bulls had higher pH values than steers. Differences between bulls and steers in pH were maintained during the 48-h cooler period.

Means for carcass traits are given in Table 1. Bull beef was darker in color and possessed more advanced lean maturity ratings than steers. Bulls were about 1 month older than steers.

Bulls had less marbling and lower quality grades than steers (Table 1). Bulls also had heavier side weights, larger 12th-rib longissimus muscle areas, and were trimmer than steers.

Cooler Temperature. Least-squares means and standard errors for high (60°F) and low (33°F) temperature treatments are given in Table 2. Lean meat (12th rib) of the 60°F temperature carcasses was slightly less mature in appearance than lean meat from the 33°F temperature treatment. Although 60°F 12th-rib longissimus lean color tended to be lighter in color than that of 33°F 12th-rib lean, the difference was not statistically significant. The practical importance of differences observed in lean maturity are questionable.

With the exception of kidney, pelvic, and heart fat (KPH), variation in the remainder of the traits observed in the cooler was not associated with temperature conditions. There is no explanation apparent to the authors for reduced amounts of KPH fat in the 33°F group.

Electrical Stimulation. Electrical stimulation had no effect on carcass temperature. Electrical stimulation did, however, result in a more rapid pH decline. The more rapid pH decline of ES sides was not associated with improved tenderness. Ultimate pH values for the ES and control sides were similar at 48 h.

Electrically stimulated sides were lighter in color and exhibited more youthful 12th-rib longissimus muscle lean maturity scores than control sides (Table 3). However, no differences in quality grades were observed between sides. Heavier weights of electrically stimulated sides (right side) are likely due to splitting errors and/or variation in KPH fat distribution. Carcasses were graded after a 48-h chill; therefore, lack of improved quality grades due to electrical stimulation was not unexpected. Previous research indicated that ES could be utilized to improve certain quality-indicating characteristics when carcasses were ribbed after a 24-h chill.

Sex condition x ES interactions for palatability traits (except

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flavor) were the only statistically significant interactions. Sensory panel means for sex x ES subclasses are presented in Table 4. Electrical stimulation improved palatability characteristics about one-half a panelist score within the steer group. However, no improvement in palatability characteristics was observed in the bulls. Steers had lower pH and carcass temperatures than bulls. The lower pH of bulls may have been associated with decreased antemortem glycogen levels of bulls. Lower glycogen levels may have prevented violent contraction required for muscle fiber disruption or lysosomal enzyme release described. However, another very likely explanation for the sex x ES interaction was that variation in tenderness in bulls is primarily related to variation in connective tissue and not variation in the myofibrillar component.

Effects of cooler temperature (CT) and sex were important for sensory characteristics. The lack of a meaningful interaction would indicate that CT affected bull and steer carcasses equally. Of interest, however, is whether or not high temperature conditioning (60°F) improved palatability of meat obtained from bull carcasses to approximate meat obtained from steer carcasses under normal chilling conditions (33°F). Means for meat from 60°F bulls for fragmentation ease, amount of connective tissue, and tenderness are generally within one-half a palatability score of meat from 33°F steers. This compared with a difference of one unit in taste panel scores for 33°F bulls *vs* 33°F steers.

It was concluded that high temperature carcass conditioning and ES were not adequate treatments to improve the palatability of meat obtained from bulls to equal meat obtained from steers. Sensory panel perceived connective tissue was highly associated with panel scores for tenderness, which suggests that variation in tenderness was affected primarily by connective tissue. Consequently, subsequent studies of the effects of sex on connective tissue and the relationship of connective tissue to palatability are recommended.

Table 1.—Means of carcass traits for bulls and steers

Trait	Bulls	Steers
Number (sides)	88	54
Color[a]	5.82	5.30
Lean maturity[b]	2.00	1.89
Marbling[c]	6.94	8.91
USDA quality grade[d]	7.11	8.39
Side weight, lb	387	316
Fat thickness, in	.3	.5
Longissmus area, in^2	13.6	10.8
KPH fat, pct	1.98	2.58
USDA yield grade	2.60	3.44

[a]Scored: 1 = light to 8 = very dark.
[b]Scored: 1 = A-, 2 = A°, 3 = A+.
[c]Scored: 6 = traces+, 7 = slight-, 8 = slight°, 9 = slight+.
[d]Scored: 7 = Good-, 8 = Good°, 9 = Good+.

Table 2.—Means of traits for high and low cooler temperatures

Trait	High (60° F)	Low (33° F)
Number	70	72
Color	5.51	5.60
Lean maturity	1.88	2.00
Marbling	7.68	8.17

Table 3.—Least-squares means of traits for electrically stimulated and control sides

Trait[a]	Stimulated	Control
Number	71	71
Color	5.33	5.78
Lean maturity	1.89	2.00
Marbling	7.97	7.88
USDA quality grade	7.82	7.69

[a]See Table 1 for a description of traits.

Table 4.—Least-squares means of sensory panel traits for sex x electrical stimulation subclasses

	Bull		Steer	
Trait[a b]	ES	Control	ES	Control
Number	43	43	27	25
Fragmentation ease[a]	5.30	5.41	6.56	6.03
Amt. connective tissue[b]	5.02	5.14	6.33	5.82
Tenderness[c]	5.25	5.36	6.57	6.06
Flavor[d]	5.27	5.51	5.73	5.46

[a]Scored: 1 = extremely difficult to 8 = extremely easy.
[b]Scored: 1 = Abundant to 8 = none.
[c]Scored: 1 = extremely tough to 8 = extremely tender.
[d]Scored: 1 = extremely bland to 8 = extremely intense.

Sex, Age, and Breed Related Changes in Bovine Testosterone and Intramuscular Collagen

H. Russell Cross, Bruce D. Schanbacher, and John D. Crouse[1]

Introduction

Castration of the male in meat-producing animals has long been a traditional practice in the production of commercial livestock. Numerous research studies have indicated that intact bovine males grow more rapidly, utilize feed more efficiently, and produce a higher yielding carcass than castrates. Even though young bulls have obvious growth and leanness advantages over steers, their meat is usually lower and more variable in tenderness than steers. These differences in tenderness have been attributed to differences in fatness or differences in connective tissue.

Factors influencing the amount and strength of intramuscular collagen have been linked to animal age, sex, and breed. The literature strongly indicates that collagen solubility decreases significantly with animal age and that most of these changes take place from birth to about 2 years of age. Results have illustrated that the age-related changes in tenderness are significantly more pronounced in bulls than in steers and heifers, particularly in muscles high in collagen. These findings suggest that age-related changes in the cross-linking of collagen might be related to the sex of the animals.

Several workers reported an increase in collagen content in young bulls at about 12 months of age. Others have suggested that the increase in collagen content at this age, which was accompanied by an increased solubility, was due to an increase in collagen synthesis related to the hormonal changes occurring during puberty in young bulls.

The objective of this phase of our research was to investigate the influence of animal age, breed, and sex condition (bull *vs* steer) on the content and solubility of intramuscular collagen using muscle biopsies in the longissimus muscle.

Procedure

Selection and management of animals. Twenty bulls and twenty steers representing four breeds (7/8 Charolais, 7/8 Simmental, Hereford, and Angus), were randomly selected for this study. At 5 months of age, the animals were placed on a ration of 78 percent corn silage (IFN 3-08-153), 10 percent corn (IFN 4-02-931), and 12 percent supplement. Rations varied as the animals matured with the final ration being 42.7 percent corn silage, 54.1 percent corn, and 3.2 percent supplement.

Muscle and blood samples. Muscle biopsy samples (approximately 10 g) from the ribeye muscle of each animal were obtained at 6, 9, 12, 15, and 18 months of age. Sampling began in the posterior portion of the muscle and continued on alternate sides to the 13th rib area. One week prior to each biopsy, blood samples were collected from each bull and steer. Serum was harvested from the blood samples and assayed for testosterone concentration.

Results

Breed effects. The influence of breed on collagen and testosterone levels is presented in Table 1. Even though total and insoluble collagen values were not significantly influenced by breed, soluble collagen and testosterone levels were. Percentage soluble collagen and testosterone were highest in the Simmental cattle, while testosterone was lowest in the Hereford cattle.

Sex effects. Sex (bull *vs* steer) had significant effects on all collagen traits (Table 2). When age and breeds were combined, the longissimus from bulls contained more soluble collagen and less total collagen. The magnitudes of the differences presented in Table 2 were not large but were significant.

Age effects. Data reported in Table 3 indicate that collagen solubility decreases with age. Also of interest in Table 3 is the relationship between total collagen and testosterone. Total collagen increased up to 12 months of age and then decreased significantly. The same trend was apparent for testosterone.

Age/sex relationships. Even though the age/sex interaction was not significant, the means are presented in Table 4 to give a clearer picture of the sex/age relationship. Total collagen increased to 12 months and then decreased in both bulls and steers. The obvious question is: Why the increase in collagen in steers when the testosterone levels were not affected by age? As expected, the soluble collagen decreased as age increased. The magnitude of the decrease was much less in bulls, particularly at 12 months. This could perhaps indicate some endocrine influence above and beyond the influence of testosterone.

Data presented add further support to the age effects on collagen cross-linking and collagen solubility. Results also reveal an interesting relationship between collagen synthesis and possible endocrine influences. These differences also appear to be influenced by breed. Other workers have reported an increase in intramuscular collagen content in bulls at 12 months of age. It appears from the present and other investigations that, for bulls, the collagen content increases near puberty.

The increased collagen synthesis near puberty would result in an increase in the proportion of immature collagen, less cross-linking, and, thus a greater proportion of collagen that would be solubilized during cooking. Since these bulls would probably be marketed at a later age (14 to 16 months), the cross-linking would be expected to continue, and the total amount of cross-linked (toughened) collagen would also be higher in bulls. The impact of this increase on tenderness will require further study, but one could hypothesize that this situation could be a significant contributor to the toughness in bulls.

In conclusion, the data from this study indicate that bulls are different from steers in regard to relative synthesis of intramuscular collagen at or near puberty. The increased synthesis of collagen appears to be influenced by testosterone or some related endocrine parameter. The mechanism of this action remains unclear.

Table 1.—The influence of breed on mean collagen and testosterone traits

Breed	n	Total collagen (mg/g)	Soluble collagen (pct)	Testosterone (ng/ml)
Simmental	10	4.97	16.99	5.21
Charolais	10	5.73	14.87	4.31
Hereford	10	5.24	15.06	2.90
Angus	10	5.66	14.43	4.97

[1]Cross is a professor of animal science, Texas A&M University (formerly research leader, Meats Unit, MARC); Schanbacher is a reproductive physiologist, Reproduction Unit; and Crouse is the research leader, Meats Unit, MARC.

Table 2.—The influence of sex on mean collagen content in the longissimus

Sex	Total collagen (mg/g)	Soluble collagen (pct)
Bull	5.75	15.92
Steer	5.05	14.76

Table 3.—The influence of age on meat collagen and testosterone traits (bulls and steers combined)

Animal age (mo)	Total collagen (mg/g)	Soluble collagen (pct)	Testosterone (ng/ml)
6	3.89	19.26	2.22
9	4.74	20.73	2.95
12	8.91	14.83	9.09
15	5.39	11.94	3.13
18	4.06	9.93	- - -

Table 4.—Age by sex interaction means for collagen traits in the longissimus

Animal age (mo)	Soluble collagen (pct)		Total collagen (mg/g)	
	Bull	Steer	Bull	Steer
6	19.63	18.88	4.03	3.75
9	21.61	19.86	4.89	4.58
12	16.74	12.91	9.99	7.83
15	11.58	12.30	5.36	5.42
18	10.04	9.83	4.49	3.64

Variation in Sensory Properties of Meat as Affected by Sex Condition, Muscle, and Postmortem Aging

Steven C. Seideman and John D. Crouse[1]

Introduction

For several decades, the sensory properties of beef, particularly tenderness, have been of interest to the meat industry. Variations in sensory properties of beef have been attributed to muscle cut or muscle and postmortem aging. The objective of this study was to examine the sensory properties of five beef muscles, determine the contribution of connective tissue (i.e., collagen) to tenderness, and investigate the response of various muscles to postmortem aging.

Procedure

Eight bulls and eight steers of similar backgrounds were slaughtered. The longissimus dorsi (LD; ribeye), psoas major (PM; tenderloin), semitendinosus (ST; eye of round), semimembranosus (SM; top round), and biceps femoris (BF; bottom round) muscles were removed from the right and left sides of each carcass 24 h postmortem. The muscles from the right sides of all carcasses were immediately frozen (24 h postmortem) while the muscles from the left sides of all carcasses were aged at refrigeration temperatures for 7 days prior to freezing.

After freezing, all muscles were cut into steaks. Steaks were used for sensory panel evaluations, shear force determinations, and compositional properties. Sensory panel evaluations were conducted using an 8-member panel. Panelists rated steaks for juiciness, ease of fragmentation, amount of connective tissue, tenderness, and flavor intensity. Cores (1.3 cm) from cooked steaks were also sheared on an Instron Universal testing machine equipped with a Warner-Bratzler shear device. One steak from each carcass and each muscle was powdered in liquid nitrogen and analyzed for percentage fat, amount of collagen (expressed on a wet basis and fat-free basis), and percentage soluble collagen.

Results

Sensory and compositional properties of five bovine muscles are shown in Table 1. The psoas major muscle was the most juicy and most tender of all muscles. Muscles were ranked in order of sensory ratings; PM>ST>LD>BF>SM. The amount of fat (intramuscular) was highest in the PM muscle and lowest in the SM muscle. The amount of collagen on a fat-free basis was ranked LD>ST>BF>PM>SM. The percentage collagen solubility was ranked LD>PM>ST>BF>SM.

Simple correlation coefficients between compositional components and tenderness and shear force at 1 and 7 days postmortem are presented in Table 2. The percentage of fat within a muscle was significantly correlated to tenderness at 1 and 7 days postmortem and to shear force at 7 days postmortem. The amount of collagen was negatively correlated to tenderness and shear force at 1 and 7 days postmortem, whereas the percentage soluble collagen was never significantly correlated to tenderness or shear force.

Mean values for tenderness and shear force stratified by muscle and postmortem aging period are shown in Table 3. Sensory tenderness ratings were not affected by aging period; however, shear force values were lower after 7 days of aging as compared to samples aged for only 1 day.

The results suggest that muscles vary considerably in tenderness, but neither the amount or the percentage collagen solubility are solely responsible for differences in the tenderness between muscles, although the amount of collagen was, by far, the more closely correlated to tenderness differences. The sensory panel tenderness ratings did not appear to reflect any differences in aged muscle samples; whereas shear force values were substantially lower for muscles aged 7 days, as opposed to muscles aged for only 1 day. Research is continuing to determine why muscles differ in tenderness.

[1]Seideman is a research food technologist and Crouse is the research leader, Meats Unit, MARC.

Table 1.—Sensory and compositional properties of five bovine muscles

Property	Muscle				
	Longissimus dorsi	Psoas major	Semitendinosus	Semimembranosus	Biceps femoris
Sensory properties					
Juiciness[e]	5.3[b]	5.8[a]	5.2[b]	4.9[c]	5.2[b]
Ease of fragmentation[f]	4.7[c]	5.9[a]	4.9[b]	4.5[c]	4.6[c]
Amount of connective tissue[g]	4.6[c]	5.9[a]	4.8[b]	4.4[c]	4.5[c]
Tenderness[h]	4.8[bc]	5.9[a]	4.9[b]	4.7[c]	4.8[bc]
Flavor intensity[i]	5.7[d]	5.9[a]	5.7[cd]	5.8[bc]	5.9[ab]
Shear force (lb)	13.39[a]	5.49[d]	8.83[c]	9.37[bc]	10.10[b]
Compositional properties					
Fat (pct)	2.67[b]	3.43[a]	2.27[b]	1.36[c]	2.17[b]
Amount of collagen (mg/g)	5.73[b]	3.18[c]	7.53[a]	5.05[b]	7.43[a]
Collagen solubility (pct)	26.7[a]	16.6[b]	15.9[b]	9.1[c]	14.5[b]
Amount of collagen (mg/g) fat free	1.54[a]	0.56[c]	1.25[ab]	0.51[c]	1.10[b]

[abcd]Means on the same line followed by a common superscript are not different.
[e]Means based on an 8-point scale (8 = extremely juicy; 1 = extremely dry).
[f]Means based on an 8-point scale (8 = extremely easy; 1 = extremely difficult).
[g]Means based on an 8-point scale (8 = none; 1 = abundant).
[h]Means based on an 8-point scale (8 = extremely tender; 1 = extremely tough).
[i]Means based on an 8-point scale (8 = extremely intense; 1 = extremely bland).

Table 2.—Simple correlation coefficients between compositional components and tenderness and shear force at 1 and 7 days postmortem

Compositional components	Tenderness		Shear force	
	1 day	7 days	1 day	7 days
Fat (pct)	0.39***	0.59***	−0.19	−0.40***
Amount of collagen	−0.42***	−0.33**	−0.42***	0.32**
Collagen solubility	−0.02	0.16	0.08	0.13

**P<0.01
***P<0.001

Table 3.—Mean values for tenderness and shear force stratified by muscle and postmortem aging period

Tenderness parameter	Postmortem aging period (days)	Muscle				
		Longissimus dorsi	Psoas major	Semitendinosus	Semimembranosus	Biceps femoris
Sensory tenderness	1	4.6	5.8	5.1	4.9	4.7
	7	4.8	5.9	4.9	4.7	4.8
Shear force (lb)	1	17.5	6.9	9.1	10.6	10.8
	7	9.6	5.4	8.1	8.3	9.1

Effects of Dietary Stress on Dark-Cutting Beef

John D. Crouse and Stephen B. Smith[1]

Introduction

The advantages of bulls compared with steers in production efficiency, performance, and carcass leanness have been well documented. However, it has also been well documented that meat obtained from bulls is darker in color and less tender than meat produced by steers. It may be concluded that the superiority in production performance of bulls over steers has not been exploited largely due to meat characteristics that differ from those of steers.

Postmortem (after slaughter) muscle color is directly associated with antemortem (pre-slaughter) muscle glycogen content, postmortem muscle pH decline, and ultimate muscle pH, which, in turn, is affected by live animal physiological stress. In several mammalian species, depletion of muscle glycogen by exercise was followed by repletion to greater content of muscle glycogen than observed before exercise. In a lab study, starvation for 48 h followed by 48 h of refeeding rats a 65 percent glucose diet resulted in an increase and "overshoot" in the activities of muscle glucose 6-phosphate dehydrogenase, malic enzyme, and muscle glycogen content. The objective of the present study was to determine the effects of fasting on bull muscle glycogen content and repletion rates.

Procedure

Animals and Diet. Four Simmental, six Hereford, and two Angus bulls were randomly assigned within breeds in equal numbers to a fasted or control group and individually penned and fed. Bulls were about 12 months of age and weighed 1,000 lb. Bulls were fed to appetite a diet (84 pct TDN) containing corn silage, corn, soybean meal, and urea for 2 months before and during the experiment.

Fasting. After having been fed the diet for 2 months, six bulls were fasted for 96 h with access to water. The six fasted animals were gradually returned to full feed over a 5-day period.

Biopsy and Glycogen Assay. All bulls were biopsied 11 days before the fast period (time period = -15 days), at the end of the fast (time period = 0 days), and 3, 7, 10, and 14 days postfasting. A needle biopsy procedure was used to obtain longissimus muscle samples on the right and left sides of the animals between the first and fifth lumbar vertebrae about 12 cm off the midline. Local anesthesia was used at time of biopsy. Glycogen was assayed by an accepted procedure.

Results

Bulls adapted well to their new environment and diet over the 2-month period before the first biopsy. Bulls also remained relatively calm when moved and handled for biopsy.

No significant interactions among breed, treatment, period, or biopsy location were observed in variation in glycogen content. Glycogen values were also similar among sampling sites within the longissimus muscle.

Fasted and control bulls had similar muscle glycogen content at days -15, 7, 10, and 14 (Table 1). Fasting for 96 h reduced muscle glycogen from 77 to 50 mol glycogen-glucose/g of tissue by day 0. Depressed muscle glycogen levels persisted through day 3 while animals were developing normal feed consumption patterns.

The repletion rate of 3 μmol glycogen-glucose·g^{-1}·day^{-1} observed in the present study from days 3 to 7 was very low. It is possible that muscle glycogen was not adequately depleted by fasting to trigger a more rapid repletion rate. Or, repletion rates in cattle are lower than those in laboratory animals. Muscle glycogen repletion rates within the fasted group were similar between days 3 to 7 and 10 to 14. Muscle glycogen-glucose content in both groups of bulls declined slightly at day 10, possibly due to undefined environmental stress incurred on that day. By day 7, muscle glycogen-glucose content of the fasted group was 9 to 12 μmol/g less than the control group; however, this difference was relatively small as compared with experimental residual error, and the values for fasted and control groups were considered equal.

Recent technological advances in postmortem processing may enhance bull beef quality. A review indicates that electrical stimulation of prerigor carcasses will improve tenderness and enhance lean color and marbling of beef. It must be noted, however, that the process is muscle energy dependent. Previously reported research indicates that electrical stimulation of prerigor bull carcasses failed to result in an improvement in meat color or tenderness. One plausible explanation for the lack of an electrical stimulation effect is that muscle glycogen reserves were not adequate to promote the desirable effects of electrical stimulation.

Results indicate that fasting to reduce muscle glycogen content and refeeding to attain a muscle glycogen "overload" is not feasible. The procedure will not serve as a management tool to attain a muscle condition that will enhance meat quality by increasing quantities of antemortem muscle glycogen. Given very low muscle glycogen repletion rates, management systems designed to prevent muscle glycogen depletion prior to slaughter appear more promising.

Table 1.—Least-squares means of glycogen by treatments over time[a]

	Time, day[b]						Residual
	-15	0	3	7	10	14	SD
Control (C).....	86	77	77	77	69	78	11
Fasted (F)	82	50	53	65	58	68	11
C minus F	4	27	24	12	11	10	

[a]μmol glycogen-glucose/g of sample reported.
[b]Length of time fed before refeeding (-15 days) and length of time after refeeding (3, 7, 10, and 14 days). Animals were fasted 96 h before day 0 (-4 to 0 days).

[1]Crouse is the research leader, Meats Unit, MARC; and Smith is an associate professor of animal science, Texas A&M University (formerly a research chemist, Meats Unit, MARC).

Muscle Fiber Studies Comparing *Bos Indicus* and *Bos Taurus* Cattle

Steven C. Seideman[1]

Introduction

Beef cattle can be classified as either *Bos taurus* or *Bos indicus*. *Bos taurus* breeds of cattle are those originating from Europe, whereas *Bos indicus* are those breeds originating from India and southeast Asia to include such breeds as Brahman, Sahiwal, Boran, etc. Because of the heat and disease resistance of *Bos indicus* breeds of cattle, they have been used intensively in the southern U.S. However, some studies have shown *Bos indicus* breeds of cattle to produce carcasses with less marbling and less tender meat than *Bos taurus* breeds. Since carcass and meat characteristics are a reflection of the muscle fiber present in the meat, a study was conducted to examine the fiber type characteristics of *Bos taurus* and *Bos indicus* breeds of cattle.

Procedure

A total of 124 *Bos taurus* x *Bos indicus* steers (1/4, 1/2, 3/4 Hereford, Angus, Pinzgauer, Brahman, and Sahiwal) were slaughtered at either 16 or 17 months of age. All steers were fed and treated alike.

After slaughter, a section of the longissimus muscle was removed from the 13th rib region at one-third the distance from the lateral end of the ribeye. The sections were wrapped in aluminum foil, frozen in liquid nitrogen, and stored in an ultralow freezer (-94°F). Transverse sections were cut 10μm thick using a cryostat and stained for alkali-stable ATPase. Stained sections were later photographed and enlarged. From the photographs, fibers were counted and classified as red, intermediate, or white muscle fibers based on staining intensity. The area of ten fibers of each type was then determined.

Results

Muscle fiber characteristics of *Bos taurus* and *Bos indicus* cross cattle are shown in Table 1. The cross-sectional areas of all muscle fibers from muscle of *Bos indicus* cattle were generally substantially larger than the areas of muscle fibers from *Bos taurus* cattle. In addition, the standard deviations of white fibers from *Bos indicus* breeds of cattle were substantially larger than the standard deviation of muscle from *Bos taurus* breeds of cattle.

The percentages of white, intermediate, and red muscle fibers (Table 1) ranged from 46.4 to 49.0 percent, 23.0 to 24.9 percent, and 27.8 to 30.3 percent, respectively. These percentages did not appear to be substantially different for any breed.

Average fiber size and adjusted fiber size (Table 1) indicate that muscle from *Bos indicus* cross cattle has larger muscle fibers than muscle from *Bos taurus* breeds of cattle.

This study has shown that muscle from *Bos indicus* cross cattle (Brahman and Sahiwal) tended to have larger muscle fibers than muscle from *Bos taurus* cross cattle (Hereford, Angus, and Pinzgauer). In this study, it was observed that muscle from cattle having large muscle fibers tended to have less marbling and produced less tender meat as opposed to muscle from cattle having small muscle fibers. This relationship of small muscle fibers to tender meat represents an important link between the cellular structure of meat and its tenderness. Further development of this concept is being pursued and may lead to an improvement in the USDA beef grading system.

[1]Seideman is a research food technologist, Meats Unit, MARC.

Table 1.—Muscle fiber characteristics of *Bos taurus* and *Bos indicus* cattle

Muscle fiber characteristic	*Bos taurus*				*Bos indicus*			
	Hereford- or Angus-X		Pinzgauer-X		Brahman-X		Sahiwal-X	
	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Fiber area								
White	3257.7	650.7	3446.5	591.1	4127.4	1023.9	3867.5	773.5
Intermediate	1979.9	428.7	2145.0	452.3	2332.5	468.9	2093.1	309.0
Red	1767.6	374.8	1812.3	370.4	1937.4	377.4	2013.5	320.6
Percentage of fibers								
White	49.0	6.2	47.3	5.1	46.4	5.9	48.3	6.6
Intermediate	23.0	5.0	24.9	5.8	23.3	4.9	23.4	4.9
Red	28.0	5.2	27.8	5.4	30.3	6.4	28.3	5.4
Ave. fiber size[a]	2335.1	388.9	2467.9	385.4	2799.1	548.2	2658.0	351.1
Adjusted ave. fiber size[b]	1273.5	219.2	1323.6	210.6	1461.2	266.0	1456.6	195.1

[a]Cross-sectional area of white, intermediate and red muscle fibers divided by 3.
[b]Cross-sectional area of the three muscle fibers adjusted for their percentage.

Contributions of Acetate, Lactate, and Glucose to the Accumulation of Fat in Intramuscular and Subcutaneous Tissues of Beef Cattle

Stephen B. Smith and John D. Crouse[1]

Introduction

The U. S. meat industry faces a dual challenge: it must reduce the fat content of meat carcasses in order to provide a nutritious product with a minimum of waste, while not affecting meat palatability. The positive effects of marbling (fat deposited within muscle) on tenderness and palatability, as well as a meat grading system that penalizes carcasses with little marbling, make it desirable that animals be produced with minimal amounts of fat stored in depots, such as the subcutaneous and perirenal depots, without markedly decreasing intramuscular adipose tissue. This can be accomplished only if the factors regulating lipid deposition in intramuscular adipose tissue and other fat depots differ substantially.

Previous studies have indicated that marbling scores are not affected by differences in diet to the extent observed for backfat thickness or total carcass fat. Therefore, the primary purpose of this study was to determine the relative contributions of acetate, lactate, and glucose as carbon precursors for fatty acid synthesis in intramuscular and subcutaneous adipose tissue. Additionally, the effects of age and diet on lipogenic activities in both depots were investigated because earlier studies have not demonstrated the interaction between age and diet on lipogenesis in either intramuscular or subcutaneous adipose tissue.

Procedure

Animals. At weaning (approximately 8 mo of age), 16 Angus steers were divided randomly into two groups and fed either a corn silage diet or a 70 percent ground corn diet. Cattle fed the ground corn diet were adapted gradually to the diet over a 30-day period. Four animals from each group, selected randomly, were slaughtered at 16 months of age, and the remainder at 18 months of age. Samples of muscle also were obtained at 12 months of age. However, the marginal intramuscular adipose tissue development at this age precluded obtaining quantities of adipose tissue sufficient for the *in vitro* incubations. Mean weights for the four groups of steers were 1,067 and 1,166 lb (16 mo, low energy and high energy, respectively), and 1,155 and 1,197 lb (18 mo, low energy and high energy, respectively). Intramuscular (marbling) and overlying subcutaneous (fat cover) adipose tissue was obtained at slaughter. Samples were used to make *in vitro* observations of adipose tissue lipogenesis. Key enzymes involved in adipose tissue lipogenesis were also assayed. Fat cell numbers and sizes were determined.

Results

Feed intake and carcass traits. Steers fed the low energy diet consumed 75 percent more feed than did steers fed the high energy diet. On a dry-matter basis, feed intake was not significantly different, although the animals on the ground corn diet consumed 14 percent more metabolizable energy.

In spite of greater carcass weights, cattle fed the ground corn diet did not display significantly greater longissimus dorsi (ribeye) surface areas or marbling scores. However, backfat thickness and kidney, pelvic, and heart fat were greater in cattle fed the ground corn diet, indicating that a large portion of the difference in carcass weights between the two groups was due to greater fat accumulation in the high energy-fed cattle. There were no significant age effects on any of the carcass characteristics.

Adipose cell size and soluble protein content. No differences in cell size, number distribution, or soluble protein content due to diet or age of steers were observed. Consequently, data were pooled across diet and age. Adipocytes obtained from intramuscular adipose tissue were substantially smaller than cells from the subcutaneous adipose tissue depot. Consistent with the smaller mean and peak diameters, intramuscular adipose tissue tended to have greater numbers of cells per gram tissue and significantly more soluble protein content than did subcutaneous adipose tissue.

Lipid synthesis. The nanomoles of lactate and glucose incorporated into the glyceride-glycerol moiety over the 3-h incubation period were similar. Some label from [U-^{14}C]acetate was recovered in glyceride-glycerol; however, this does not represent a net synthesis of glycerol-3-phosphate from acetate; rather a net flow of tricarboxylic acid cycle intermediates to glyceride-glycerol. The incorporation of all three precursors into glyceride-glycerol was significantly greater in subcutaneous than in intramuscular adipose tissue. Furthermore, the incorporation of lactate and glucose into glyceride-glycerol increased with age in subcutaneous adipose tissue, regardless of diet.

Glyceride-fatty acid synthesis did not change with age in intramuscular adipose tissue, nor was it influenced by diet. Acetate and lactate incorporation into fatty acids was markedly greater in subcutaneous adipose tissue than in intramuscular adipose tissue. The highest acetate and lactate incorporation into fatty acids was observed in subcutaneous adipose tissue from steers fed the high energy diet. Conversely, glucose incorporation into fatty acids was significantly greater in intramuscular adipose tissue than in the subcutaneous depot. The lower incorporation of glucose into glyceride-fatty acids in the 18-month-old steers relative to the 16-month-old steers was likely because of the elevated acetate and lactate incorporation observed in these animals, causing increased dilution of the acetyl-CoA pool and increased competition for available coenzyme A.

When the incorporation of lipogenic precursors into fatty acids was expressed as a percentage contribution to fatty acid synthesis, glucose was quantitatively the primary lipid precursor in intramuscular adipose tissue. Acetate provided 70 to 80 percent of the acetyl units to fatty acid synthesis in subcutaneous adipose tissue. Acetate's contribution to lipogenesis in intramuscular adipose tissue was substantially less (10 to 26 pct). Lactate contributed the same percentage acetyl units in both adipose tissue depots.

Feeding cattle a diet rich in grain typically results in animals with greater backfat thicknesses and percentage kidney, pelvic, and heart fat relative to animals fed corn silage or roughage diets. Changes in marbling scores generally are less dramatic than associated increases in backfat thickness in grain-fed cattle, and substantial increases in backfat thickness due to grain feeding have been observed even in animals that do not display increased marbling scores. The lesser sensitivity of the intramuscular adipose tissue depot to dietary manipulations, relative to subcutaneous adipose tissue, suggests that lipogenesis in the two depots is not regulated in a coordinated manner.

When acetate and glucose also were present in the incubation media, lactate provided the same proportion of acetyl units to lipogenesis in intramuscular and subcutaneous adi-

[1]Smith is an associate professor of animal science, Texas A&M University (formerly a research chemist, Meats Unit, MARC); and Crouse is the research leader, Meats Unit, MARC.

pose tissues (15 to 30 pct). The importance of acetate as a lipogenic precursor was greatly reduced in the intramuscular adipose depot; the basis for this major difference between depots is unknown.

In summary, several *in vitro* similarities exist between intramuscular and subcutaneous adipose tissue. However, the relative insensitivity of marbling scores and lipogenic activities in intramuscular adipose tissue to changes in age or diet, in conjunction with the greater importance of glucose as a lipogenic precursor in the intramuscular adipose depot, indicate that the potential exists to manipulate fat deposition in other depots without adversely affecting marbling scores, and hence palatability.

Energy Utilization by Hereford and Simmental Males and Females

Calvin L. Ferrell and Thomas G. Jenkins[1]

Introduction

Observed growth of cattle during the postweaning period reflects the genetic potential for growth as modified by the environment. Various breeds or breed crosses of cattle have been characterized for postweaning liveweight gain under *ad libitum* feeding conditions. Previous results showed calves by Simmental males had greater rates of postweaning gain than those sired by Hereford males. Simmental-sired steers were more efficient during a weight-constant interval, of equal efficiency during a time-constant interval and less efficient to a fat-constant end point than Hereford-sired steers. Differences among breeds in efficiencies of energy utilization for maintenance and gain have been reported. Similarly, differences among sexes (or sex condition) in growth rate and carcass characteristics have been documented. Efficiencies of energy utilization for maintenance and gain of castrate males have been reported to be similar to those of females. However, other results have suggested that intact males had higher maintenance requirements than castrate males.

This paper describes the accretion of total empty body weight, water, fat, protein, and energy by Hereford and Simmental males and females in response to differing rates of metabolic energy (ME) intake. Estimates of breed and sex effects on ME requirements for maintenance and efficiencies of utilization of ME for maintenance and gain are reported.

Procedure

Hereford and Simmental intact males and females (18 of each breed x sex group) were obtained from the research center herds about two weeks after weaning (210 days of age). Six calves of each breed x sex group were assigned to one of 12 pens and allowed a 28-day period for adjustment to the diet and to individual feeding by electronic headgates. One pen of calves of each breed and sex was fed a high concentrate diet at a low, medium, or high (*ad libitum)* level. The diet contains 1.38 Mcal ME/lb and 13.9 percent crude protein. Calves were fed individually, once daily, for about 212 days.

One Hereford male (low), two Hereford females (one low, one high), three Simmental males (two high, one low) and two Simmental females (medium) were removed from the study due to failure to adapt to the electronic headgates, poor health, or death. The data reported describe a total of 64 animals that remained on the study.

All calves were weighed at the initiation of the study and at 28-day intervals until completion. The individual food allowances of restricted groups were based on each individual's initial weight. Feed allowances were adjusted at 28-day intervals to maintain daily intakes per unit metabolic body size ($kg^{0.75}$). At 84 days into the study, feed allowances of calves assigned to the restricted levels were adjusted upward because of low or negative weight gains. Unconsumed feed was collected and weighed weekly throughout the feeding period. Samples of feed were taken daily, frozen, composited at 28-day intervals, and subsequently analyzed for dry matter and crude protein. On day 0 and about day 212, deuterium oxide was used to estimate body composition.

Results

Hereford females weighed less and contained less water and protein but more fat than Hereford males at the start of the study (Table 1). Neither liveweight nor any of the empty body components differed significantly between Simmental males and females at this time, but Simmental cattle had greater total weights and weights of water and protein than Hereford cattle. The empty bodies of Hereford males, Simmental males, and Simmental females contained similar proportions of water, fat, and protein. Hereford females tended to contain lower proportions of water, a higher proportion of fat, and a similar proportion of protein when compared to other animals. These results suggest that Hereford heifers, possibly because of a high propensity toward fatness and a relatively low impetus for lean growth, had begun to fatten at an earlier age than other animals included in the study.

Simmental cattle had greater daily ME intakes (Table 2) than Hereford cattle, and males had greater daily ME intakes than females. The observed differences reflected, in part, the experimental design, since low and medium intakes were governed by body size, but also resulted from the initial weights and rates of gain achieved by cattle assigned to the different treatments. Simmental cattle gained empty body weight slightly faster than Hereford cattle, and males gained weight more rapidly than females. Hereford males gained fat and energy slightly more rapidly than Hereford females, whereas Simmental males gained fat and energy less rapidly than Simmental females. Protein and water gain of Hereford and Simmental cattle were similar at restricted levels of intake, but gains of these components were greater for Simmental than for Hereford at *ad libitum* intakes. Similarly, rates of protein and water gain increased more rapidly in response to increased intake by males as compared to females. Hereford males and females tended to gain energy at similar rates, but Simmental males gained energy less rapidly than Simmental females.

These results were consistent with observations made of composition of rib section soft tissue of these cattle at slaughter. Results of other studies in which breeds or breed crosses differing in growth potential or sex are consistent with data obtained in this study on cattle fed *ad libitum*. These results further document that at *ad libitum* intakes, total weight of components of lean tissue (water and protein) gains of Simmentals were greater than those of Herefords; however, this advantage was not observed at lower intake levels. Similar results were observed when males were compared to females. These results indicate the benefits that may result from increased potential for weight or lean tissue gain may be realized only if the environment is suitable to support the greater gains.

Simmental cattle had greater ($P<.05$) ME requirements for maintenance (energy stasis) than Hereford cattle, and males had greater requirements than females. The ME available for gain did not differ significantly between breed or sex groups, but energy gain of Herefords was greater than that of Simmentals. Efficiency of utilization of ME for maintenance or gain of Herefords was greater than that of Simmentals. These results are consistent with previous reports which showed that Simmental or Simmental-cross cattle had greater requirements for maintenance than Angus or Hereford cattle. Other reports indicated Hereford cattle had lower requirements for maintenance than Holsteins, and that Angus or Hereford steers had lower predicted basal metabolic rates than Friesian steers. Results from these and various other studies have often been interpreted to indicate that body protein has a higher energy cost of maintenance and a lower efficiency of gain than body fat. Other data has been interpreted to indicate that cattle with a greater genetic potential for growth have greater maintenance requirements than those with less potential for growth.

[1]Ferrell is a research animal scientist, Nutrition Unit, and Jenkins is a research animal scientist, Production Systems Unit, MARC.

Table 1.—Initial animal weights and weights of empty body chemical components

	Hereford		Simmental	
	Male	Female	Male	Female
No. of animals	17	16	15	16
Liveweight, lb	514	470	666	644
Empty body weight, lb	459	423	602	580
Empty body water, lb	320	273	419	401
Empty body fat, lb	30	52	38	38
Empty body protein, lb	88	80	119	111
Empty body energy, MJ	1,409	1,700	1,831	1,785

Table 2.—Daily metabolizable energy (ME) intake and gains of empty-body components

						Daily empty body gains				
Breed	Sex	Ration	No. of animals	Days on feed	ME intake MJ/day	Total weight, lb	Water, lb	Fat, lb	Protein, lb	Energy, MJ
Hereford	Male	Low	5	212	36.8	.64	.22	.29	.10	6.12
		Medium	6	215	58.5	1.68	.76	.56	.28	12.60
		High	6	206	87.8	2.58	.93	1.12	.41	23.94
	Female	Low	5	209	33.6	.53	.16	.26	.08	5.43
		Medium	6	212	48.8	1.32	.58	.47	.22	10.45
		High	5	211	82.6	2.18	.69	1.06	.34	22.20
Simmental	Male	Low	5	211	49.9	.64	.31	.19	.11	4.47
		Medium	6	214	67.8	1.72	.93	.41	.31	10.31
		High	4	215	103.0	2.82	1.53	.67	.50	16.76
	Female	Low	6	206	47.1	.71	.28	.29	.11	6.08
		Medium	4	207	58.4	1.26	.40	.60	.20	12.56
		High	6	210	96.8	2.45	.96	.99	.40	21.49

Table 3.—Means for utilization of metabolizable energy (ME) by Hereford and Simmental males and females

	Breed		Sex	
Item[a]	Hereford	Simmental	Male	Female
ME intake	872	894	898	868
Maintenance	446	530	514	462
ME for gain	426	363	385	406
Energy gain	198	148	165	182
Maintenance efficiency	.66	.62	.63	.65
Gain efficiency	.49	.42	.43	.48

[a]ME intake, maintenance, ME for gain and energy gain are expressed as $KJ/kg^{0.75}/day$. Efficiency values are expressed as kJ/kJ.

Oxidative Metabolism of Gravid Uterine Tissues of the Cow

Calvin L. Ferrell and Lawrence P. Reynolds[1]

Introduction

Early reports suggested fetal growth is an energetically efficient process; however, more recent reports have suggested fetal growth to be a relatively inefficient process. These latter reports were based on indirect estimates obtained by the use of indirect calorimetry or comparative slaughter approaches, whereas the earlier data resulted from acute *in vivo* and *in vitro* approaches. Methodologies have been developed to directly measure rates of oxidative metabolism of tissues of the gravid uterus of cows using chronic preparations. The objective of this study was to quantify rates of oxidative metabolism of gravid uterine, fetal and utero-placental tissues of the pregnant cow and to determine how these variables change with stage of gestation.

Procedure

Mature (3 to 11 yr), multiparous Hereford cows were mated to Simmental bulls. Cows were fed a corn silage based diet (10.6 MJ metabolizable energy, 120 g crude protein per kg) at approximately maintenance. Surgery was performed on cows at about 132 (12 head), 176 (8 head), 220 (11 head), and 245 (7 head) days after mating. At surgery, indwelling catheters were placed in a uterine artery, uterine vein, umbilical vein, fetal femoral artery, and fetal femoral vein of cows at 176 and 220 days of gestation. Similar procedures were followed in surgeries performed on cows at 132 and 245 days of gestation, except catheters were placed in a placental artery and two placental veins rather than in the fetal femoral vessels and umbilical vein. Tips of the catheters were placed close to the umbilical vessels.

All measurements were taken at approximately five days after surgery. Uterine and umbilical blood flows were determined by diffusion equilibrium procedures by the use of deuterium oxide (D_2O) as the marker substance. Samples of blood were collected into heparinized blood collecting tubes for subsequent oxygen determinations and into test tubes containing ethylenediamine tetraacetate (EDTA) for subsequent D_2O, glucose, and lactate determinations. Oxygen, D_2O, and lactate concentrations in blood and glucose concentrations in plasma were determined.

Results

Uterine blood flow increased about 4.5 fold during the interval of gestation encompassed by this study, whereas umbilical blood flow increased about 21 fold during this interval (Table 1). Relationships of uterine and umbilical blood flow to day of gestation (t) were as follows:

uterine blood flow, l/min = $.479e^{.0129t}$ SE = .18, R^2 = .91, N = 31
umbilical blood flow, l/min = $.011e^{.0245t}$ SE = .24, R^2 = .94, N = 24

These regressions show that umbilical blood flow was lower initially but increased at a rate about twice as great as that of uterine blood flow. This finding is consistent with the more rapid rate of fetal growth compared to growth of other gravid uterine tissues.

Concentrations of oxygen, glucose, and lactate in samples from the uterine artery or umbilical vein remained constant across stage of gestation (Table 1). Uterine artery-uterine vein and umbilical vein-umbilical artery concentration differences likewise remained constant across stages of gestation, except that uterine artery-uterine vein oxygen concentration difference increased during the latter stages. Mean concentration differences were similar to those observed in previous studies. Since concentration differences changed little, uterine and fetal uptake changes primarily reflected changes in uterine and umbilical blood flows. These data indicate, as do those reported previously, net uptakes of oxygen and glucose by the gravid uterus, fetus, and utero-placenta of pregnant cows and a net loss of lactate from the utero-placenta to both the fetus and maternal circulations. Fetal glucose uptake was 3.3, 11.1, 15.9, and 16.2 percent of gravid uterine glucose uptake at 137, 180, 226, and 250 days of gestation, and fetal oxygen uptake was 19.9, 48.6, 58.5, and 55.2 percent of gravid uterine oxygen uptake at those stages, respectively. Estimates of fetal respiratory quotients (RQ) suggest that glucose and lactate uptakes, if entirely oxidized, could account for about 33 and 26 percent of fetal oxidative metabolism, respectively. These data indirectly show that although glucose and lactate are important energy substances, other substances must be important sources of energy for the bovine fetus.

The data are also indicative of a high rate of oxidative metabolism of utero-placental tissues as compared to that of the fetus. Oxygen uptake of the fetus was 26, 94, 141, and 176 percent of that of the utero-placenta at 137, 180, 226, and 250 days of gestation, respectively; however weights of these tissues vary greatly during this interval. When expressed relative to weight of tissue, oxygen uptake of the fetus was relatively constant (255 μmole/kg/min). Oxygen uptake by the utero-placenta (460 μmole/ kg/min) was nearly two fold greater than that of the fetus.

Total heat production of the gravid uterus, calculated from the data presented in Table 1, assuming 21.1 kJ/liter O_2, was 1.37, 2.12, 4.87, and 8.57 MJ/day at 137, 180, 226, and 250 days of gestation. The heat increment of gestation (the total increase in heat production of pregnant over non-pregnant cows) is about 2.69, 7.36, 12.34, and 14.95 MJ/day at these times. Thus, heat production of gravid uterine tissues appear to account for about 44 percent of 8.57 MJ/day at 137, 180, 226, and 250 days of gestation. Thus, heat production of gravid uterine tissues appear to account for about 44 percent of heat increment of gestation. These results are in concert with early reports which suggested maternal energy expenditure increased during pregnancy in addition to that utilized by gravid uterine tissues.

Rates of energy accretion in the gravid uterus, fetus, and utero-placenta may be calculated. Gross efficiency of energy accretion of each of these tissues can then be calculated as energy accretion divided by the sum of energy accretion and heat production. The resulting gross efficiency of energy accretion in gravid uterine, fetal, and utero-placental tissues were 27, 39, and 15 percent, respectively. These results suggest that fetal growth *per se* is a relatively efficient process. However, the efficiency of fetal growth is not readily observable because of the relatively low efficiency of energy accretion in the utero-placental tissues which are required to support fetal growth directly and because of the apparent increase in maternal metabolism, which may be required to support fetal growth less directly.

[1]Ferrell is a research animal scientist and Reynolds is a postdoctoral research associate, Nutrition Unit, MARC.

Table 1.—Some components of oxidative metabolism of gravid uterine tissues of the cow

Variable[a]	Day of gestation				SE
	137	180	226	250	
Uterine blood flow	2.93	4.78	8.75	13.21	.29
Umbilical blood flow	.28	1.07	2.79	5.87	.25
Uterine arterial oxygen	6.121	6.558	6.263	6.371	.008
Umbilical venous oxygen	4.200	4.140	4.242	4.257	.075
Uterine arterial glucose	4.588	4.526	4.502	4.831	.109
Umbilical venous glucose	2.531	2.162	2.679	2.097	.084
Uterine arterial lactate	.639	.484	.580	.560	.043
Umbilical venous lactate	1.721	1.582	2.243	2.223	.140
Uterine A-V oxygen	.684	.663	.830	.968	.039
Umbilical v-a oxygen	1.520	1.409	1.500	1.291	.045
Uterine A-V glucose	.279	.260	.219	.284	.026
Umbilical v-a glucose	.098	.127	.109	.117	.014
Uterine A-V lactate	−.054	−.063	−.054	−.081	.012
Umbilical v-a lactate	.123	.085	.134	.088	.030
Uterine oxygen uptake	2.01	3.11	7.15	12.58	.28
Fetal oxygen uptake	.40	1.51	4.18	6.95	.24
Utero-placental oxygen uptake	1.51	1.60	2.97	3.97	.24
Uterine glucose uptake	.58	.84	1.32	2.61	.14
Fetal glucose uptake	.019	.093	.210	.424	.026
Utero-placental glucose uptake	.40	.66	1.11	2.51	.16
Uterine lactate uptake	−.142	−.289	−.581	−1.125	.079
Fetal lactate uptake	.047	.091	.326	.625	.051
Utero-placental lactate uptake	−.19	−.38	−.91	−1.67	.12

[a]Blood flows are liters/min, metabolite concentrations and arterial-venous (A-V) veno-arterial (v-a) concentration differences are millimoles/liter and millimoles/min. Glucose concentrations were determined in plasma; lactate concentrations were determined in whole blood.

Mineral Accretion During Prenatal Growth of Cattle

Calvin L. Ferrell, Dan B. Laster and Ronald L. Prior[1]

Introduction

Published data on prenatal (fetal) growth in cattle have been limited primarily to birth weights or weights and linear measurements of fetuses at different stages of gestation. Others have provided data describing fetal growth in terms of weight, nitrogen, and energy. These and other data have provided insight into the rates of protein and energy accumulation by the fetus during development and serve as bases for the estimation of protein and energy requirements for fetal development. Objectives of the present study were to describe the patterns of calcium (Ca), phosphorous (P), sodium (Na), potassium (K), magnesium (Mg), iron (Fe), and zinc (Zn) accretion in bovine fetuses and to estimate requirements of these minerals for pregnancy in cattle.

Procedure

Angus, Hereford, and Red Poll crossbred yearling heifers (732 lb) were mated to five half-sibling Brown Swiss bulls. Heifers (81 head) which were diagnosed pregnant at 35 to 42 days postmating were assigned on the bases of weight and breed cross to one of three pens and fed diets that were equal in nitrogen content to achieve maternal weights gains of approximately 0 (low), 1.1 (medium), or 2.2 (high) lb/day. Heifers (three to seven) from each treatment group were slaughtered at about 120, 150, 180, 210, 240, and 255 days postmating at a commercial facility.

Reproductive tracts were recovered at slaughter. Weights of each total gravid (pregnant) uterus, then weights of separate components—fetus, fetal fluids (allantoic and amnionic), uterus, cotyledons, and placenta (fetal membranes with cotyledons removed)—were obtained. Fetal sex was recorded. Fetuses were frozen at −29°F and later ground, mixed, and sampled. Dry matter was determined on duplicate samples by drying in a forced-air oven.

Duplicate samples of each fetus were ashed. Ashed samples were then analyzed for Ca, P, Na, Mg, Fe, and Zn content. Data were analyzed by regression analysis.

Results

Fetal weight and mineral content at different stages of gestation, estimated from regression analyses, are presented in Table 1. Ca and P contents of bovine fetuses increased with gestation. Others have observed a more rapid increase of these minerals in fetuses of dairy cows. The Ca to P ratio in this study was 1.1 at 100 days of gestation and increased to about 1.6 at 280 days, whereas previous data indicated the Ca to P ratio to be about 1.4 at 140 days and about 1.8 near term. The differences between these studies may be attributed largely to differences in the breeds of cattle involved. The results of this study demonstrated that the Ca to P ratio was not constant but increased as the fetus developed. These results were a reflection of the different distribution of Ca and P in the body as well as the different growth patterns of the different tissues.

Although total fetal Na and K contents increased during gestation (Table 1), Na concentration decreased. Others have observed that fetal Na concentration decreased but that K concentration increased during gestation.

The Mg content of bovine fetuses (Table 1) increased 200 fold from 100 days postmating to 280 days. Few data were found for comparison with these values. The Fe content of bovine fetuses increased 160 fold from 100 to 280 days postmating. No data were found for comparison with these values. Zn content of bovine fetuses increased 160 fold from 100 to 280 days of gestation.

Daily rates of fetal weight, Ca, P, Na, K, Mg, Fe, and Zn gains (Table 2) at different stages of gestation were obtained by differentiation of the relationships between total fetal content of these minerals and days of gestation with respect to day of gestation. The values obtained were considered to be estimates of the rates of accretion of the various fetal components on different days postmating. These values indicated that daily rates of accretion of all fetal components increased during early and mid-gestation, reached a maximum at about 250 days and then decreased. Previously, we have observed a decline in the rate of increase in fetal weight, energy, and nitrogen gain, but did not observe an actual decrease in the rate of fetal growth. The observed decrease may have been due to a breed of sire x breed of dam interaction and to parity of the dam. These data demonstrated that accretion rates in bovine fetuses of all minerals were small during the first two trimesters of gestation but relatively large during the last trimester.

Mineral accretion rates in nonfetal gravid uterine tissues were estimated from the rate of weight change in the uterus, fetal membranes, and fetal fluids at different stages of gestation and from literature values on the mineral contents of these tissues.

The accretion rates of each mineral in each nonfetal uterine tissue at each stage of gestation were combined with estimates of fetal mineral accretion. Results are presented in Table 3. Comparison of Table 3 to Table 2 reveals that mineral accretion in the nonfetal uterine tissues was small in relation to mineral accretion in the fetal component. Thus, even though errors may be associated with the estimates of non-fetal mineral accretion, these appear to be of little significance in relation to total gravid uterine mineral accretion.

Ca and P accretion rates in the gravid uterus (Table 3) were lower, especially during the latter stages of gestation, than reported by others. These differences appear to be due largely to the breeds of cattle used in the data base. Previously reported values were derived from estimates of the Ca and P contents of the fetuses from dairy cows and from gravid uterine growth curves of Red Danish cattle, both of which resulted in higher values late in gestation than observed in the crossbred fetuses used in this study. Rates of Na and K accretion in gravid uterine tissues were slightly lower than estimates obtained previously, but estimates of Mg accretion rates were much lower in this study. These estimates were based on estimates of the Mg content of calves at birth. This value is about twofold higher than that observed in the present study. No data were found for comparison with the Fe and Zn accretion rates observed in this study.

The rates of accretion of the various minerals in the gravid uterus provide estimates of minimal net amounts of the minerals evaluated that need to be available to the uterus for development of the gravid uterine tissues at various stages of gestation in cattle of similar type. Estimates of daily allowances of Ca, P, Na, K, Mg, Fe, and Zn (Table 4) were calculated assuming availabilities of 45, 45, 100, 100, 20, 50, and 50 percent, respectively. It should be recognized that availabilities vary depending on mineral source, maturity, physiological state of the animal, etc. Ca availability, for example, may range from about 20 to 100 percent.

The data provide estimates of daily allowances of several minerals for pregnant beef cattle. The allowances obtained should be added to maternal allowances to obtain estimates of total mineral allowances during pregnancy in cattle.

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Table 1.—Weights of various fetal components at various stages of gestation[a]

Day of gestation	Fetal							
	Weight, lb	Ca, g	P, g	Na, g	K, g	Mg, g	Fe, g	Zn, g
100	.77	1.11	1.00	.69	.55	.054	.015	.004
130	2.7	5.05	3.96	2.35	1.96	.203	.056	.017
160	7.8	18.3	12.9	6.62	5.71	.645	.172	.057
190	18.8	53.1	34.6	15.3	13.7	1.71	.442	.153
220	37.7	123	76.2	29.2	26.8	3.80	.943	.331
250	63.1	227	138	45.9	43.2	7.07	1.67	.577
280	87.5	334	205	59.3	57.1	11.0	2.46	.810

[a]1g = .0022 lb.

Table 2.—Daily weight gain and mineral gain by the bovine fetus at various stages of gestation[a]

Day of gestation	Fetal							
	Weight, g	Ca, g	P, g	Na, g	K, g	Mg, mg	Fe, mg	Zn, mg
100	16	.06	.05	.030	.025	3	7	.2
130	47	.24	.17	.089	.076	8	2.3	.7
160	115	.72	.47	.207	.185	23	5.9	2.1
190	224	1.68	1.02	.380	.352	51	12.5	4.5
220	345	2.97	1.75	.534	.515	90	20.9	7.3
250	400	3.78	2.27	.542	.545	125	26.7	8.6
280	313	3.07	2.04	.316	.343	129	24.2	6.2

[a]1g = .0022 lb.

Table 3.—Daily mineral gain by the bovine uterus at various stages of gestation.

Day of gestation	Gravid uterine component[a]						
	Ca, g	P, g	Na, g	K, g	Mg, mg	Fe, mg	Zn, mg
100	.07	.08	.18	.08	8	4.9	1.5
130	.25	.21	.27	.14	15	7.4	2.3
160	.73	.53	.41	.26	32	12.1	3.1
190	1.69	1.09	.61	.44	61	19.6	6.7
220	2.98	1.82	.76	.61	101	28.1	9.6
250	3.79	2.34	.76	.63	124	32.8	10.5
280	3.08	2.09	.48	.41	136	28.6	7.6

[a]1g = .0022 lb, 1mg = .001 g.

Table 4.—Estimated daily allowances of various minerals for pregancy in cattle[a]

Day of gestation	Ca, g	P, g	Na, g	K, g	Mg, mg	Fe, mg	Zn, mg
100	.16	.18	.18	.08	.04	9.8	3.0
130	.56	.47	.27	.14	.08	14.8	4.6
160	1.62	1.18	.41	.26	.16	24.2	6.2
190	3.76	2.42	.61	.44	.31	39.2	13.4
220	6.62	4.04	.76	.61	.51	56.2	19.2
250	8.42	5.20	.76	.63	.62	65.4	21.0
280	6.84	4.64	.48	.41	.68	57.2	15.2

[a]Availabilities used to estimate allowances of various minerals were: Ca, 45 percent; Na, 100 percent; K, 100 percent; Mg, 20 percent; Fe, 50 percent; Zn, 50 percent. See text for details.

Effects of Chronic Environmental Heat Stress on Blood Flow and Nutrient Uptake by the Uterus and Fetus of the Pregnant Cow

Lawrence P. Reynolds, Calvin L. Ferrell, John A. Nienaber, and Stephen P. Ford[1,2]

Introduction

Chronic exposure of pregnant cows to elevated environmental temperatures results in decreased birth weights of calves. This phenomenon is economically important since reduced birth weights are associated with decreased calf survival and growth. The adverse effects of environmental heat stress on fetal development have been greater than can be explained by a reduction in maternal feed intake or length of gestation.

The rate of uterine blood flow seems to be a primary determinant of nutrient uptake by the gravid (pregnant) uterus, and acute heat stress on days 120 to 130 of gestation has been shown to decrease uterine blood flow in ewes. The effects of chronic heat stress on uterine or umbilical blood flows, however, have not been determined. It has been suggested that chronic heat stress causes a decrease in uterine blood flow, thereby reducing the supply of nutrients available for development of gravid uterine tissues. The objectives of this study were to determine if the adverse effects of chronic environmental heat stress on calf fetal development were related to changes in blood flow and/or nutrient uptake of the gravid uterine tissues.

Procedure

The estrous cycles of a group of mature (3 to 8 yr old) nonpregnant Hereford cows (mean wt 1,131 lb) were synchronized by using two injections of Lutalyse (prostaglandin $F_{2\alpha}$), given at 11-day intervals. Simmental bulls were penned with the cows from 42 to 102 h after the second injection of Lutalyse. For all cows, day 0 of gestation was defined as the middle of the breeding period (i.e., 72 h after the second injection of Lutalyse). On day 100 of gestation (December 1, 1983), pregnant cows were assigned randomly to control (8 head) or heat-stressed (8 head) treatment groups. Control cows were stanchioned in a heated barn (thermostat set at 60°F), whereas heat-stressed cows were stanchioned in temperature- and humidity-controlled environmental chambers set to maintain a regimen of 82°F for 12 h (5:00 p.m. to 5:00 a.m.) and 97°F for 12 h (5:00 a.m. to 5:00 p.m.) daily, with a dewpoint of 69.8°F. Actual temperatures and relative humidities in the barn and environmental chambers were recorded continuously on a hygrothermograph. Rectal temperatures were obtained daily at 5:00 p.m. for control and at 5:00 a.m. and 5:00 p.m. for heat-stressed cows by using a rectal thermometer.

Feed was withheld from cows for 48 h and water for 12 h before surgery, which was performed on day 163 ± 4 of gestation. Each cow was moved to an individual pen inside a heated (approximately 72°F) surgery building 12 h before surgery and was moved back to the barn or environmental chamber within 24 h after surgery. While the cows were under general anesthesia, catheters were surgically implanted in the uterine artery, uterine vein (of the cow), and in the umbilical vein, femoral artery, and femoral vein (of the fetus).

Six days after surgery, a priming dose (24 cc) followed by a constant infusion (0.39 cc/min) of an antipyrine solution (12.5 g/100 cc 0.9 pct NaCl) was administered into the fetal femoral vein catheter. Blood samples from the uterine artery and uterine vein (10 ml), as well as umbilical vein and fetal artery (4 ml), were collected and placed on ice at 60, 90, 120, 150, and 180 min after the antipyrine infusion began. Blood samples also were collected before and at 90 and 180 min after infusion began, into heparinized capillary tubes for determination of oxygen (O_2) content. All blood samples were analyzed for antipyrine and O_2 within 30 min of collection. During the antipyrine infusion procedure, maternal and fetal heart rates were determined by visual observation of pulses in the arterial catheters. The rectal temperature of each cow also was recorded during the infusion procedure. Each cow received a second surgery five days after the antipyrine infusion, at which time weights of the fetus and various fetal organs were obtained.

Blood samples were analyzed for concentrations of glucose, lactate, amino acid nitrogen (N), and urea N. Uterine and umbilical blood flows were determined (steady-state diffusion method). Uterine, fetal, and utero-placental uptakes of O_2, glucose, lactate, amino acid N, and urea N were also calculated. Data were analyzed statistically and are reported as least-squares means ± standard error.

Results

The barn in which control cows were stanchioned maintained a mean temperature of 64°F and relative humidity of 50 percent, as determined from the hygrothermograph recordings. During the 12-h "hot" period, heat-stressed cows were subjected to an average temperature of 97°F and relative humidity of 50 percent. During the 12-h "cool" period, average temperature was 82°F and relative humidity 65 percent. Maternal and fetal heart rates on the day of antipyrine infusion were similar between heat-stressed and control cows (66.4 ± 5.1 and 154.4 ± 4.6 *vs* 65.2 ± 4.7 and 150.0 ± 4.6 beats/min). Rectal temperatures, however, were greater ($P<.03$) for heat-stressed compared with control cows (103.8 ± 0.4 *vs* 102.7 ± 0.2°F). Uterine and umbilical blood flows of heat-stressed cows were about 30 percent less ($P<.05$) than those of control cows (Table 1). When expressed as blood flow per lb of tissue, blood flows of heat-stressed cows still were less than those of control cows. Fetal weights also were less ($P<.10$) for heat-stressed cows (Table 1).

The concentration of all metabolites measured in this study (O_2, glucose, lactate, amino acid N, and urea N) were similar in blood from the umbilical vein of heat-stressed and control cows (Table 2). Concentrations of O_2, lactate, amino acid N, and urea N in blood from the uterine artery also were similar for both treatment groups. The concentration of glucose, however, in blood from the uterine artery, was less ($P<.10$) in heat-stressed cows (Table 2). Even though a slight difference in concentration of glucose in the uterine artery was observed, the concentration differences in the uterine vein and artery, umbilical vein, and fetal artery for all metabolites were similar between the groups (Table 2). Uptake of all metabolites by the gravid uterus tended to be less for heat-stressed than for control cows; however, this difference was significant ($P<.10$) only for urea N (Table 3). Uptakes of O_2 and glucose were less for fetal and placental tissues of heat-stressed compared with those of control cows (Table 3). Utero-placental secretion of urea N also was reduced ($P<.05$) in heat-stressed cows. Weights of liver, kidney, and heart of fetuses from heat-stressed cows were less than for those of controls (Table 4). Weights as a proportion of fetal weight also were less for fetal liver and heart of heat-stressed cows. Weights of semitendinosus muscle and

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[2]These data have been published previously in the Journal of Agricultural Science (Cambridge), Vol. 1, 1985.

brain were not different between groups (Table 4).

These data demonstrate that chronic environmental heat stress during mid-gestation has adverse effects on fetal growth and development in beef cows. The 13 percent reduction in fetal weight in the present study is somewhat greater than previous reports of reduced birth weights of calves from dairy cows subjected to environmental heat stress during the last one-third of gestation. Birth weight of lambs from ewes subjected to chronic heat stress during pregnancy has been reported to be reduced by 7 to 66 percent. The effect of heat stress on lamb birth weight has been observed even when ewes are fed to maintain body weights similar to those of controls. In addition, in previous studies, chronic heat stress had no effect on length of gestation in ewes or cows. Thus, the effects of chronic environmental heat stress on fetal development cannot be explained totally by reductions in maternal feed intake or length of gestation.

In the present experiment, the decrease in liver and heart weights of fetuses from heat-stressed cows was not proportionate to the decrease in fetal weight. In addition, a decrease in kidney weight was observed for fetuses of heat-stressed cows. There was no significant effect of heat stress on weights of fetal muscle or brain. The effects of chronic heat stress during pregnancy on fetal organ weights in ewes have varied. The effects of restriction of maternal dietary energy intake also differ depending upon the fetal organ measured in ewes and cows. These inconsistent effects of heat stress and dietary energy restriction on the fetal organs might be explained by the observation that organs of the fetus develop at different rates during gestation. In the present study, fetal organs characterized by early (brain) or late (muscle) development were not affected by heat stress, but organs expected to be developing rapidly during the experimental period (liver, kidney, and heart) were affected.

Although uptake of nutrients by the uterus and fetus were reduced by heat stress, the most significant effects seemed to be on the utero-placenta. These data agree with previous reports of a 40-50 percent reduction in weight of placentas from heat-stressed ewes, even though fetal weights were reduced by only about 30 percent. In ewes, an experimentally induced decrease in placental weight is associated with decreased birth weight of lambs as well as decreased fetal liver and heart weights, whereas fetal plasma glucose and lactate concentrations are not different from those of control fetuses. These previous reports are similar to results obtained in the present study. The reduced fetal and utero-placental nutrient uptakes observed in the present study probably resulted from decreased uterine and umbilical blood flows, because uterine artery vein and umbilical vein-umbilical artery differences were similar between heat-stressed and control cows.

Whether fetal and utero-placental functions were decreased as a result of decreased blood flow is not known. It is likely that heat stress reduces uterine and umbilical blood flows, which leads to a decrease in nutrient uptakes of the uterine tissues and, ultimately, to a decrease in fetal growth. The mechanisms whereby chronic heat stress reduces blood flow to the uterus of pregnant ruminants is not known. During acute heat-stress in sheep, the percentage of cardiac output passing through the skin is increased. It has been suggested that exposure to high temperatures during pregnancy might result in diversion of blood from certain organs, including the uterus, to others such as the lungs and respiratory tract, which are concerned in heat regulation. These possibilities warrant further investigation.

Table 1.—Blood flow of the gravid uterus and fetus in control and heat-stessed cows[a]

Treatment group	Fetal wt (lb)[b]	Total blood flow (liters/min)		Blood flow per lb tissue (liter/lb/min)	
		Uterine	Umbilical	Uterine[c]	Umbilical
Control	12.94 ± 0.57(6)[d]	6.12 ± 0.49(8)[e]	1.34 ± 0.05(4)[e]	0.888 ± 0.068(8)[e]	0.467 ± 0.015(4)[d]
Heat stressed	11.22 ± 0.70(4)	4.27 ± 0.62(5)	0.96 ± 0.07(2)	0.617 ± 0.085(5)	0.414 ± 0.022(2)

[a]Least-squares means ± standard error (number of cows in parentheses).
[b]Fetal weights on day 174 ± 4.
[c]Gravid uterine weights were calculated from the data of Ferrell, Garrett, and Hinman (J. Anim. Sci., 42:1477-1489, 1976).
[d]P<.10 for treatment differences.
[e]P<.05 for treatment differences.

Table 2.—Metabolite concentrations and arterial-venous differences in control and heat-stressed cows[a]

Metabolite	Treatment group	Maternal		Fetal	
		Uterine artery	Uterine artery-uterine vein	Umbilical vein	Umbilical vein-fetal artery
Oxygen (mM)	Control	6.31 ± 0.18(8)	0.71 ± 0.07(8)	3.93 ± 0.30(4)	1.38 ± 0.07(3)
	Heat stressed	5.76 ± 0.25(4)	0.80 ± 0.10(4)	3.96 ± 0.43(2)	1.43 ± 0.09(2)
Glucose (mM)	Control	4.50 ± 0.15(7)[b]	0.24 ± 0.04(7)	2.06 ± 0.30(4)	0.19 ± 0.05(4)
	Heat stressed	4.00 ± 0.20(4)	0.20 ± 0.05(4)	1.95 ± 0.35(3)	0.10 ± 0.07(2)
Lactate (mM)	Control	1.09 ± 0.09(8)	−0.15 ± 0.03(8)	3.02 ± 0.42(4)	0.10 ± 0.03(4)
	Heat stressed	0.84 ± 0.13(4)	−0.14 ± 0.04(4)	2.57 ± 0.49(3)	0.13 ± 0.04(2)
Amino acid N (meq/liter)	Control	18.70 ± 0.73(8)	0.26 ± 0.16(8)	26.29 ± 1.03(4)	1.73 ± 0.41(4)
	Heat stressed	18.47 ± 1.03(4)	0.03 ± 0.23(4)	28.31 ± 1.20(3)	1.10 ± 0.59(2)
Urea N (meq/liter)	Control	5.01 ± 0.89(8)	−0.12 ± 0.05(8)	5.84 ± 1.29(4)	0.19 ± 0.14(4)
	Heat Stressed	5.54 ± 1.26(4)	−0.02 ± 0.06(4)	3.58 ± 1.49(3)	−0.10 ± 0.20(2)

[a]Least-squares means ± standard error (number of cows in parentheses).
[b]P<.10 for a metabolite within a column.

Table 3.—Uptakes of metabolites by gravid uterus, fetus, and utero-placenta of control and heat-stressed cows[a]

Metabolite	Treatment group	Gravid uterus	Fetus	Utero-placenta
Oxygen	Control	4.39 ± 0.48(8)	1.87 ± 0.14(3)[b]	4.49 ± 0.22(3)[c]
(mmol/min)	Heat Stressed	3.54 ± 0.68(4)	1.34 ± 0.18(2)	1.75 ± 0.28(2)
Glucose	Control	1.17 ± 0.27(7)	0.17 ± 0.03(4)[b]	1.62 ± 0.29(4)[b]
(mmol/min)	Heat stressed	0.71 ± 0.36(4)	0.06 ± 0.42(2)	0.39 ± 0.41(2)
Lactate	Control	−0.77 ± 0.18(8)	0.13 ± 0.02(4)	−0.78 ± 0.29(4)
(mmol/min)	Heat Stressed	−0.57 ± 0.25(4)	0.12 ± 0.03(2)	−0.73 ± 0.40(2)
Amino acid N	Control	1.70 ± 0.85(8)	1.45 ± 0.30(4)	1.97 ± 1.73(4)
(meq/min)	Heat stressed	−0.26 ± 1.21(4)	0.70 ± 0.43(2)	−0.54 ± 2.45(2)
Urea N	Control	−0.49 ± 0.16(8)[b]	0.16 ± 0.12(4)	−0.88 ± 0.10(4)[c]
(meq/min)	Heat stressed	−0.14 ± 0.29(4)	−0.08 ± 0.16(2)	−0.01 ± 0.14(2)

[a]Least-squares means ± standard error (number of cows in parentheses).
[b]P<.10 for a metabolite within a column.
[c]P<.05 for a metabolite within a column.

Table 4.—Organ weights for fetuses of control and heat-stressed cows[a]

Treatment group	Liver	Kidney	Heart	Semitendinosus muscle	Brain
Control	276.8 ± 16.3[d]	41.8 ± 3.2[b]	40.9 ± 3.5[c]	17.1 ± 1.8	62.6 ± 3.7
	(5.3 ± 0.2)[d]	(0.8 ± 0.1)	(0.8 ± 0.1)[b]	(0.3 ± 0.1)	(1.3 ± 0.1)
Heat stressed	160.5 ± 20.3	31.1 ± 4.0	27.5 ± 4.3	12.8 ± 2.2	63.9 ± 4.6
	(4.0 ± 0.2)	(0.7 ± 0.1)	(0.6 ± 0.1)	(0.3 ± 0.1)	(1.4 ± 0.2)

[a]Least-squares means ± standard error in grams. Organ weight as a proportion of fetal weight (g/100 g) in parenntheses. Six cows in the control and four cows in the heat-stressed groups.
[b]P<.10 for treatment differences.
[c]P<.05 for treatment differences.
[d]P<.01 for treatment differences.

Role of Insulin in Regulating Metabolism in Beef Cattle

Ronald L. Prior, Stephen B. Smith, and Harry J. Mersmann[1]

Introduction

Hormonal mechanisms are undoubtedly involved in regulating nutrient supply and utilization at the tissue level. The endocrine regulation of metabolism and its dietary control in ruminants have received only sporadic attention. There can be no doubt that insulin, secreted by the β cells of the islets of Langerhans in the pancreas, is at the center of metabolic regulation in ruminants as in other mammalian species. It is generally thought that insulin 1) stimulates lipogenesis and inhibits lipolysis; 2) inhibits gluconeogenesis and glucose release from the liver; 3) stimulates the uptake and utilization of glucose by many peripheral tissues; 4) stimulates the uptake and incorporation of amino acids into protein; and 5) inhibits proteolysis. However, because of differences in metabolism between the nonruminant and the ruminant, insulin may have somewhat different functions in the ruminant. As a result of microbial fermentation in the rumen, little glucose is derived directly from the gastrointestinal tract of ruminants. Ruminants utilize acetate instead of glucose as a major substrate for energy storage and oxidation in the fed state and are almost totally dependent on gluconeogenic pathways for provision of glucose in the fed state as well as during fasting. This glucose is derived mainly via gluconeogenic pathways from propionate, lactate, glycerol, and amino acids. The hormonal responses to nutrient intake in ruminants, therefore, should favor acetate oxidation or incorporation into fat concurrent with the maintenance of high rates of glucose synthesis to preserve metabolic homeostasis. The role of insulin in the removal of large glucose loads is clearly less important in ruminants than in species absorbing large amounts of glucose.

Insulin Effects on Adipose Tissue. Insulin is generally thought to stimulate lipogenesis and inhibit lipolysis. However, the limited available data in the ruminant are not convincing that this is the case. Insulin (0.5-100 mU/ml) effects on *in vitro* fatty acid synthesis from glucose or acetate in sheep or cattle were minimal or absent. In the bovine animal, 95 percent of the glucose carbon incorporated into tissue lipids was in the glyceride-glycerol fraction, whereas almost 100 percent of the acetate carbon incorporated into lipids is recovered in fatty acids. Thus, the stimulation of acetate incorporation into fatty acids by insulin may result from increasing the availability of α-glycerophosphoric acid for glyceride-glycerol production. At least a portion of the stimulation of acetate incorporation into lipids in the presence of glucose *in vitro* is caused by increased glyceride-glycerol formation. Glucose and lactate are much greater stimuli than insulin for *in vitro* lipogenesis.

Glucose infusion *in vivo* induces lipogenesis and lipogenic enzymes in adipose tissue of fed steers. However, after a 72-h fast, glucose infusion enhanced only slightly the stimulus of refeeding on inducing lipogenic activity in adipose tissue. Other gluconeogenic precursors (propionate and lactate) also had some stimulatory effects on lipogenesis in the fed steer. From these results, it was postulated that insulin was involved in the stimulation of the lipogenic process in adipose tissue, because both glucose and propionate are known to stimulate insulin release. However, in later studies, daily injections of insulin (1 U/kg for eight days) did not produce a sustained increase in lipogenesis as measured by *in vitro* incorporation rates of [^{14}C]acetate into fatty acids and lipogenic enzyme activities in bovine adipose tissue. The infusion of glucose to maintain normal blood glucose levels in addition to the insulin injections produced a sustained increase in adipose tissue lipogenesis. Thus, *in vivo* data would also suggest that glucose is a more potent stimulus than insulin for lipogenesis.

Results

Steers were fasted for 96 h and then refed. On the first day of refeeding, eight steers were treated with alloxan (45 mg/lb), and four of these received insulin to control hyperglycemia. Insulin treatment of alloxan steers significantly decreased plasma glucose (Fig. 1) as well as lactate, free fatty acid, and triglyceride concentrations toward normal over the 10-14 day-period after alloxan treatment. Further results from these studies (Table 1) suggested that insulin was necessary for a rebound in rates of acetate and lactate incorporation into fatty acids *in vitro* in adipose tissue (Table 1), but stimulation of acetyl-CoA carboxylase (Table 1) did not require insulin, because as great or greater induction of activity of this enzyme on refeeding was observed in alloxan steers as in the controls or alloxan-plus-insulin treated steers. This is in direct contrast to data in rat liver where insulin is absolutely required for the adaptive synthesis of fatty acid synthetase and acetyl-CoA carboxylase.

Insulin treatment of normal sheep has been shown to decrease plasma glycerol and free fatty acid concentrations. Insulin decreases the net appearance of glycerol in the portal vein and has been shown to decrease glycerol and free fatty acid output by ovine adipose tissue. Glucose and insulin depress the *in vitro* epinephrine-stimulated rate of fatty acid release in isolated bovine adipose cells. Long-term insulin injections (3.5 U/kg^{75}day) also depress lipolytic activities of adipose cells. However, Metz and van den Bergh reported that insulin affected neither basal nor norepinephrine-stimulated *in vitro* lipolysis in bovine adipose tissue slices. Insulin has been shown to promote the activity of adipose tissue lipoprotein

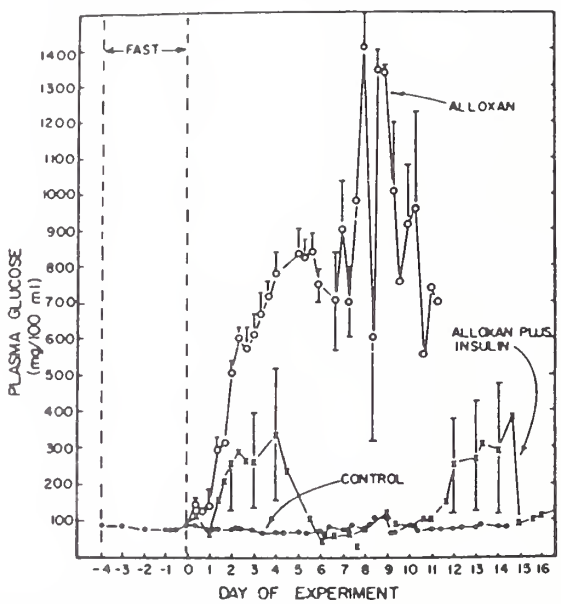

Figure 1—Plasma glucose concentrations during a 4-day fast and following refeeding in 1) alloxanized (45 mg/lb) steers, 2) alloxanized steers treated with insulin, and 3) untreated control steers in experiment 1. Data presented as means of four steers per treatment group. Vertical lines indicate ± 1 SEM.

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lipase. Glucose and insulin were found to stimulate lipoprotein lipase activity in the adipose tissue of dairy cows—findings similar to those for nonruminant species. The increased lipoprotein lipase activity and increased α-glycerophosphoric acid in the adipose tissue elicited by glucose and insulin favor the deposition of fat, just as high levels of dietary fat increased lipoprotein lipase activities in adipose tissues from lambs and steers.

Thus, the primary effects of insulin on adipose tissue of the ruminant appear to be to increase the uptake of glucose and availability of α-glycerophosphoric acid and to stimulate lipoprotein lipase with the net overall effect of increasing triglyceride deposition.

Insulin Effects on Muscle Growth and Metabolism. During exercise, glucose may supply up to 27 percent of the fuel of respiration, and, during resting conditions (either fed or fasted), essentially all of the glucose carbon taken up by muscle is returned to the blood in the form of lactate. Metabolism of acetate accounts for less than 2 percent of the oxygen uptake in the hind limb of starved or exercising animals. Little information is available on the effects of insulin on energy metabolism in muscle tissue of ruminants.

In nonruminant species, insulin lowers plasma amino acid levels by promoting the uptake and/or depressing the release of amino acids by tissues. Insulin has almost immediate effects on muscle protein synthesis, or at least on increasing amino acid incorporation into a large number of different proteins, with no evidence of a selective stimulation by insulin. The level of insulin is probably the most important factor regulating protein balance in skeletal muscle. Insulin increases the accumulation of labeled amino acids by muscle, although this accumulation may be selective for only certain amino acids. Plasma levels of the branched-chain amino acids increase markedly in alloxan-diabetic steers, and insulin therapy normalized and maintained (Fig. 1) concentrations of these amino acids. Thus, insulin or insulin plus glucose appears to stimulate the removal of branched-chain amino acids from plasma. It is also of interest that leucine is the only amino acid that promotes protein synthesis and inhibits protein breakdown in muscle tissue. Even though insulin appears to have marked effects on protein anabolism, consistent effects on growth or nitrogen balance have not been observed.

In conclusion, insulin has been shown to have effects on carbohydrate, lipid, and amino acid metabolism in the ruminant. Perhaps undue importance has been placed on the role of insulin in regulating glucose and lipid metabolism with relatively little emphasis on amino acid and protein metabolism. Insulin's role in the regulation of metabolism in adipose tissue may be more indirect than direct. Insulin undoubtedly has an effect at the cell membrane of several tissues to increase the space occupied by glucose. Increased glucose availability increases α-glycerophosphoric acid production in adipose tissue and, therefore, would increase fatty acid esterification with the net effect of increasing lipid deposition in adipose tissue. Stimulation of lipoprotein lipase by glucose and insulin would also result in increased plasma triglyceride hydrolysis and adipose tissue retention of fatty acids released from circulating triglycerides. There is no direct evidence that insulin by itself is needed for induction of lipogenic enzymes in adipose tissue in the ruminant. By increasing protein synthesis and decreasing proteolysis in muscle tissue and decreasing glycerol release from adipose tissue, smaller quantities of gluconeogenic precursors would be available to the liver for glucose synthesis with the net effect that liver glucose output would be decreased. More studies are needed in ruminants on the role of insulin in regulating branched-chain amino acid metabolism and how this affects muscle protein biosynthesis. In the authors' view, the important and obvious action of insulin on glucose utilization in the nonruminant has, in the past, tended to direct attention away from the significance of insulin on protein metabolism. It is clear from the information presented that insulin has major protein anabolic functions. Future research may strengthen the hypothesis that insulin's major role may be in altering protein synthesis and deposition.

Table 1.—Relative substrate incorporation rates and enzyme activities in adipose tissue of alloxan-diabetic steers with or without insulin therapy

Enzyme	Treatment	Rate at day 0	Day of refeeding[b]		
			3	7	14
Acetate	Control	1.24 ± 0.49	420[c]	213	173
	Alloxan	1.69 ± 0.79	114	15[c]	---
	Alloxan + insulin	0.53 ± 0.26	560[d]	655[d]	35[c]
Lactate	Control	0.86 ± 0.35	169[c]	115	88
	Alloxan	1.07 ± 0.41	78	42	---
	Alloxan + insulin	0.40 ± 0.12	315[d]	195[c]	270
Acetyl-CoA carboxylase ...	Control	1.10 ± 0.75	195[d]	202[d]	358[d]
	Alloxan	0.34 ± 0.14	576[d]	447[d]	---
	Alloxan + insulin	0.90 ± 0.74	246[d]	238[d]	129

[a]Four steers per treatment group were fasted for 96 h and limited refeeding was begun on day 0. Data expressed as nanomole per minute per gram wet weight.
[b]Data are expressed as a percentage of the enzyme incorporation rate or activity on day 0.
[c]Significantly greater than day 0 ($P<0.10$, paired t test).
[d]Significantly greater than day 0 ($P<0.05$, paired t test).

Nutrient Absorption by Lambs and Beef Cattle Fed High Forage or High Concentrate Diets

Robert A. Britton, Gerald B. Huntington, and Ronald L. Prior[1]

Introduction

A better understanding of nutrient digestion, absorption, and metabolism is essential to improve growth rate and feed efficiency in ruminants. Absorption and metabolism of nutrients, such as glucose, lactate, and amino acids, are ones which may be affected greatly by sources and level of energy in the diet. Actual amounts of these nutrients being absorbed and available for utilization have not been characterized well in ruminants. The research being reported here describes nutrient absorption and glucose and lactate metabolism in cattle and sheep fed two basic diets, alfalfa and an 85 percent concentrate diet.

Procedure

Experiment 1. Six crossbred ewe lambs with an average liveweight of 61 lb were kept indoors in elevated steel pens. Temperature was maintained at about 75°F. A 14-h light, 10-h dark cycle was maintained daily throughout the experiment. The lambs were placed under general anesthesia for surgical implantation of tygon cannulas in the portal vein (liver), mesenteric vein (intestines), and femoral artery (thigh).

The six lambs were fed alfalfa hay in 6.35 mm diameter pellets about two weeks before surgery and until the first para-aminohippuric acid (PAH) infusion and blood sampling period, which was at least one week after surgery. (PAH was infused into the mesenteric vein as a blood flow marker.) This and subsequent diets were fed via automatic feeders that dispensed the daily ration every 2 h in 12 approximately equal portions. Water was available *ad libitum* throughout the experiment. After the first PAH infusion and blood sampling, concentrate level in the diet was gradually increased to 85 percent concentrate during a period of 15 days. This was accomplished by feeding mixtures of hay and concentrate pellets. The 85 percent concentrate diet (Table 1) was also pelleted (6.35 mm diameter) and was fed for 13 days. The interval between the first and second infusions was at least 28 days.

On days of infusion a catheter for isotope infusion was inserted into the jugular vein. Each lamb was given a primer dose of radioactive glucose (tritium labeled) and lactate (carbon 14-labeled) followed by continuous infusion of each isotope for several hours.

Experiment 2. Three crossbred steers (mean weight 594 lb) were kept in individual stalls and maintained on pelleted alfalfa hay for several weeks before surgery. The steers were anesthetized, and the portal vein was entered and catheterized. Mesenteric and femoral artery catheterization procedures and preparation and maintenance of catheters were similar to those used with sheep.

After surgery, the steers were returned to the individual stalls and allowed to recover for at least one week prior to proceeding with a protocol similar to that used in the sheep experiment (Experiment 1). At least three days before the first and second infusions, they were fed via automatic feeders that dispensed a daily ration in 24 portions. For both infusions, the steers were moved to elevated steel metabolism crates. The crates were in a room maintained at 70°F and with lighting from overhead fluorescent lights on a 16-h light, 8-h dark daily cycle. A primer dose of 15 ml of PAH was injected and followed by a continuous infusion at 114.6 ml/h for a 3-h period. Primer doses and continuous infusion of radioactive glucose and lactate were administered for several hours as in the sheep experiment.

After the first infusion, the steers were returned to their individual stalls, and the dietary concentrate level was increased gradually to 85 percent (Table 1) over a period of 15 days as previously described. Net portal absorption, portal utilization, and total portal absorption were calculated.

Net portal absorption and ^{14}C-glucose specific activity were calculated on data available from all sample times. Turnover and interconversion data involving specific activity determinations for ^{3}H-glucose and ^{14}C-L-lactate were calculated on data obtained on arterial samples from the last 100 min of each infusion.

Results

Both steers and lambs exhibited increased portal blood flow, increased net portal D-lactate and glucose absorption, increased L-lactate turnover rate, and decreased percentages of glucose derived from L-lactate in response to increased concentration intake (Table 2). Within diets, steers and lambs had similar values for net portal D-lactate absorption, L-lactate turnover rate, and percentage of glucose from L-lactate (hay diet) and for net portal L-lactate absorbed and conversion of L-lactate to glucose (85 pct concentrate diet). Glucose turnover rate increased in lambs but decreased in steers in response to increased concentrate intake. Net portal L-lactate absorption as a percentage of turnover rate remained relatively constant in lambs but decreased in steers. Dry matter intake during the five days before each isotope infusion and blood sample collection was about the same for lambs but increased slightly for steers. ME intake/kg$^{0.75}$ was higher for lambs than for steers at both dietary concentrate levels. Although protocol was similar for the two experiments, one difference was that lambs were not moved from their customary environment for infusions, but the steers were moved from their stalls to another building for infusions.

We conclude that, with the possible exception of glucose turnover rate, steers and lambs responded similarly to increased concentrate intake. Rates of net portal glucose absorption and glucose turnover suggest a difference in the pattern of dietary starch digestion and subsequent site and extent of glucose absorption. This difference appears to be attributable to the greater daily feed intake for lambs than for steers.

Diet did not significantly affect the portal venous-arterial concentration difference or the net portal appearance rate of any of the amino acids in sheep or cattle (Table 3). Lack of statistical significance in some cases may be due to the small number of animals used as well as the variability in the portal plasma flow rate and venous-arterial concentration differences, although plasma samples were analyzed in duplicate to reduce variability due to analytical procedures. In concentrate-fed sheep, there was a trend for the net portal appearance of all amino acids, except aspartate, to be increased over that in hay-fed sheep. This trend existed even though the crude protein content of the hay was higher than the crude protein content of the concentrate diet.

The general pattern of portal amino acid appearance in our studies is similar, both qualitatively and quantitatively between sheep and cattle when expressed on a metabolic body size basis. Exception to this pattern are a marked decrease in net appearance of glutamate and glutamine in cattle as compared to sheep. Glutamate and glutamine can serve as shuttles for

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alpha-amino N and carbon between tissues. Most data in sheep indicate that glutamate and glutamine are taken up by the portal-drained viscera, whereas our data would suggest a net glutamine release.

Although the pattern of amino acids appearing in the portal circulation is similar between sheep and cattle (except for alanine, glutamate, and glutamine), utilization at the tissue level appears to differ somewhat between species, and extrapolation from one species to the other, relative to utilization of amino acids and responses to dietary alterations, would be somewhat premature.

Table 1.—Composition (pct of dry matter) of concentrate diet and alfalfa hay

	Diets	
Ingredient	Concentrate	Hay
Ground corn	77.94	
Ground alfalfa hay	10.00	100.0
Soybean meal	5.00	
Calcium chloride (88 pct)	0.88	
Trace mineralized salt	0.50	
Vitamin A, D, E premix[ab]	+	
Pellet binder[c]	5.68	
	100.00	100.0
Nutrient Composition		
Dry matter[d], pct	91.0 ± 0.7	93.1 ± 0.6
Crude protein[d], pct	11.9 ± 0.8	15.0 ± 0.0
Metabolizable energy[e], Mcal/kg	2.9	2.0

[a]To provide 1,000, 100, and 10 IU A, D, and E per kg diet, respectively.
[b]Thompson-Hayward Chemical Co., Omaha, Nebraska.
[c]Binder was lignin sulfonate.
[d]Based upon nine or ten separate laboratory analyses.
[e]Calculated ME composition based upon NRC.

Table 2.—Comparison of portal blood flow, net portal absorption, and metabolic interrelationships of lactate and glucose in lambs and steers

	Diet			
	Alfalfa hay		85 pct concentrate	
Item	Lambs	Steers	Lambs	Steers
Body wt, $kg^{0.75}$	12.1	66.6	12.9	67.9
Daily dry matter intake, $g/kg^{0.75}$	88.6	67.6	82.1	73.9
Daily metabolizable energy intake, $MJ/kg^{0.75}$	0.761	0.594	1.075	0.968
Portal blood flow, $liters/h/kg^{0.75}$	6.48	9.09	8.11	13.77
Net portal absorption, $mmoles/h/kg.^{075}$				
D-Lactate	0.11	0.13	0.14	0.25
L-Lactate	0.34	0.50	0.51	0.51
Glucose	–0.22	–0.69	0.63	–0.42
Turnover, $mmoles/h/kg^{0.75}$				
L-Lactate	2.79	2.79	3.79	5.29
Glucose	2.35	4.79	4.13	3.34
L-Lactate absorption, pct turnover	12.26	16.05	13.09	10.79
L-Lactate to glucose, $mmoles/h/kg^{0.75}$	0.46	1.22	0.45	0.47
Glucose from L-lactate, pct	10.09	11.17	5.51	9.62

Table 3.—Comparison of net portal amino acid appearance rates (moles/h per $kg^{0.75}$) in beef cattle and sheep

Amino Acids	Cattle	Sheep
Essential		
Lysine	57.6	62.0
Histidine	19.1	24.1
Arginine	36.8	40.9
Threonine	35.2	50.8
Methionine	15.3	14.5
Valine	40.6	67.5
Isoleucine	36.0	53.1
Leucine	70.7	103.3
Phenylalanine	54.5	54.7
Total	365.8	470.9
Nonessential		
Cysteine	- - - -	- - - -
Aspartate	–0.6	–1.5
Serine	98.3	86.8
Glutamate	–73.3	–6.2
Proline	- - - -	- - - -
Glycine	144.4	138.4
Alanine	18.6	184.4
Tyrosine	41.5	45.9
Asparagine	75.0	65.1
Glutamine	–0.9	108.2
Citruline	43.4	51.4
3-Methylhistidine	–0.7	5.1

Weather and Climate Impacts on Beef Cattle

G. LeRoy Hahn[1]

Introduction

The pervasive nature of weather and climate and the difficulties in adequately predicting their impact on beef cattle often lead to inadequate management strategies and tactics, resulting in a situation of coping as the need arises. This can lead to "management by crises" rather than rational decisions. The objective of this report is to summarize some of the known responses of cattle to their thermal environment and to address ways by which adverse impacts can be reduced. The discussion is based on results from MARC and other research stations.

General observations: Domestic cattle fall into two main classifications: European *Bos taurus* breeds (e.g., Herefords, Angus, Shorthorns, and the so-called exotic breeds) which evolved in temperate or cold regions and *Bos indicus,* or Zebu, breeds which evolved in tropical regions. *Bos taurus* breeds carry genes for higher production potential in moderate to cold climates when nutrition and other factors are non-limiting. In hot weather, the *Bos taurus* breeds are more susceptible to reduced performance than *Bos indicus* cattle, although the latter can also be adversely affected by heat effects on physiological and productive functions. The adaptability of cattle to relatively low temperatures is the result of several factors, including heat produced during roughage digestion, tissue, and a relatively lower surface area to mass ratio than for smaller species, which minimizes the rate of heat loss per unit of mass.

Body temperature represents the integrated response of an animal to various internal and external factors. Body temperature stability is generally considered an essential element for maximum productivity of cattle. However a diurnal cycling of up to 2°F body temperature can occur even in quite moderate thermal conditions. Constancy of body temperature, *per se*, may be less important to productivity than disruption of the normal cycling of body temperature caused by weather or other potential stressors. The impact of that disruption on physiological factors is presently unknown but may ultimately be expressed in terms of production, reproduction, efficiency and health. Obviously, the impact of cold or hot conditions on beef cattle performance needs to be assessed as a basis for rational management.

Performance responses to weather and climate

Conditions for optimal performance of farm animals have generally been established in terms of air temperature. Figure 1 shows temperature ranges for optimal performance and critical temperatures and also provides information on broader temperature zones wherein production and efficiency losses are nominal. The variance of acceptable conditions in terms of life stages is also illustrated. The impact of the thermal environment on nutritional requirements of cattle, reviewed by the National Research Council in 1981 ("Effect of Environment on Nutrient Requirements of Domestic Animals," National Academy Press, Washington, D.C.), indicated the effect to be significant in either extreme heat or extreme cold. Reproductive processes such as spermatogenesis, conception, and embryo survival are particularly vulnerable to high temperatures. Young calves are susceptible to cold weather because of relatively large surface area to mass ratios, small amounts of insulative tissue, and little or no heat produced by fermentation processes in the rumen.

The degree to which losses from depressed performance and death are related to the thermal environment is dependent to some extent on condition of the animals, dietary energy levels, health status, etc. An indication of such losses can be obtained from relationships developed from feedlot data in eastern Nebraska (Table 1). Feedlot No. 1 data were from 50,000 animals (60 pct Angus crossbreds, 30 pct Herefords, and 10 pct Charolais) fed during approximately 100-day periods in a commercial unit between August 1977 and April 1980. Feedlot No. 2 data were from 700 animals (Hereford, Angus, and Hereford-Angus crossbreds) kept in MARC feedlot pens for 250- to 270-day periods between 1972 and 1979. Those weather factors primarily associated with cold conditions were indicated to be most strongly related to deaths, although four of the five significant terms in the death loss equation (Feedlot No. 1) were related to heat stress (reflecting hot, humid, calm conditions). The weight gain relationship for Feedlot No. 1 indicated that cold, windy days with snow present in the winter or hot, humid summer conditions had the most effect on gain/day. Average wind speed and the diurnal temperature range were the factors of highest influence on gain/day of animals in Feedlot No. 2; however, the gain/day equation for Feedlot No. 1 predicted gain/day for Feedlot No. 2 with the same level of accuracy as the equation developed solely from Feedlot No. 2 data. Weather was more strongly related to cattle deaths than to weight gain variations; weather variables for Feedlot No. 1 in Table 1 accounted for 86 percent of the death variance and 36 percent of the gain variance.

These results to some extent reflect the finality of the death measure as opposed to the potential for recovery from weather effects on short term gains during the longer-term total feeding period. Results of this study further indicate that temperature alone is inadequate to represent the impacts of weather. Humidity, precipitation, and wind speed are strong modifiers of temperature effects; likewise, solar radiation is undoubtedly a further modifier of temperature, but data were unavailable for these analyses.

Financial losses from the pervasive weather-related gain reductions far exceeded those resulting from the relatively few deaths in the above study. To illustrate this point, the direct financial loss for each animal attributable to cold weather, based on the results of this study, is $14.14 (cattle in the feedlot for 100 days with 30 days having minimum temperatures below 0°F; value of animal at marketing = $.60/lb). The value of animals lost by death, again based on results of this study and the same assumptions, is less than 10 percent of the weather-related gain reductions.

A large-scale Colorado study to evaluate the effects of cold weather on digestion, growth, and efficiency of feedlot animals indicated that cold slightly reduced daily dry matter intake while increasing the net energy for maintenance requirement, resulting in reduced gains and feed efficiency. However, some partially offsetting positive effects were also found, including approximately 1 percent lower crude protein requirement and the ability of cattle to use relatively greater proportions of non-protein nitrogen at 32°F compared with 68°F.

The impact of winter weather conditions over a 15-year period, evaluated in terms of growth and feed conversion for beef cattle as predicted by the AGNET Beef Grower Model[2], was

[1]Hahn is an agricultural engineer, Agricultural Engineering Unit, MARC.

[2]Based on recent analyses as described in the preceding paragraphs, the current Beef Grower Model may not adequately reflect the influence of adverse weather conditions. However, use of the current model to compare variations among years, as described in this paragraph, should remain valid on a relative basis.

Table 1.—Relationships between mortality or gain and weather factors for feedlot cattle

Feedlot

No. 1: Death loss = $8.33 + 0.003W_{35} - 0.286W_{30} - 0.089W_1 - 0.343W_{33} + 0.416W_{23}$

Gain/day = $1.24 - 0.006W_{19} - 0.006W_{22} + 0.004W_{33}$

No. 2: Gain/day = $- 0.484 + 0.114W_{28} + 0.049W_7$

Where the weather factors are defined as follows for the feeding period:

W_1 = percentage of days for which temperature exceeded 80°F
W_7 = percentage of days with a temperature range greater than 45°F
W_{19} = percentage of days with snow cover
W_{22} = percentage of days with THI* greater than 79
W_{23} = percentage of days with THI* greater than 84
W_{28} = average wind speed (mph)
W_{30} = percentage of days with average wind speed less than 4.5 mph
W_{33} = percentage of days with average windchill** over 1200 base value
W_{35} = sum of THI degree-days above 84 base value

THI = Temperature-Humidity Index = $0.55t_{db} + t_{dp} + 17.5$
where t_{db} = drybulb temperature, °F
t_{dp} = dewpoint temperature, °F

**Windpchill = $(10.5 + 10\sqrt{V/3.28} - V/3.28)(50.78 - t_{db}/1.8)$ in kcal/m² – hr
where V = windspeed, ft/sec
t_{db} = drybulb temperature, °F
Values greater than 1200 indicate "bitterly cold" conditions.

Table 2.—Relative effects of winter weather on beef cattle growth and feed conversion for a 15-year period at Grand Island, Nebraska, based on the AGNET Beef Grower Model using actual weather records

	Standard Conditions[a]		Hock-Deep Mud[b]		Mud + HE Diet[c]		Description of Winter Season	
For Winter Period Starting Oct 1	Growth	Feed Conv.	Growth	Feed Conv.	Growth	Feed Conv.	Temperature	Snow
1964	99.1	101.2	99.4	100.5	100.6	99.3		
1965	101.1	99.3	100.8	98.9	101.2	98.8		
1966	100.6	99.3	100.8	99.1	101.2	99.1	Above normal	Below normal
1967	100.6	99.2	100.4	99.4	99.9	99.7	Near normal	Much below normal
1968	99.1	100.8	98.5	101.0	99.3	101.1	Below normal	Much above normal
1969	99.6	100.2	98.5	101.1	99.9	100.1	Near normal	Near normal
1970	100.1	100.1	99.4	100.4	99.3	100.4	Near normal	Slightly above normal
1971	101.1	99.3	99.9	99.7	99.9	100.0	Near normal	Much below normal
1972	100.1	99.9	99.4	100.2	99.3	100.4	Near normal (Dec. cold)	Much above normal
1973	100.6	99.2	100.4	99.0	100.6	98.8	Near normal	Much above normal
1974	99.6	100.6	99.0	100.8	99.9	100.0	Near normal (Feb. cold)	Slightly above normal
1975	101.1	98.7	100.8	98.6	100.6	99.3	Above normal	Slightly above normal
1976	100.1	99.7	99.4	99.8	99.3	100.7	Near normal (cold early, mild later)	Slightly below normal
1977	99.1	101.0	99.9	100.0	100.6	99.3	Near normal (mild early, cold later)	Above normal
1978	98.2	101.8	98.5	101.0	98.1	102.0	Much below normal	Much above normal

[a]"Standard Conditions" refer to medium-frame Hereford-Angus crossbred steers of average condition, fed a medium energy diet (NEG/NEM = 37/67) on a hard-surfaced lot.
[b]"Standard Condition" except a dirt lot which became hock-deep mud at temperatures between 25 and 45°F.
[c]"Standard Condition" except for a dirt lot with cattle fed a high energy diet (NEG/NEM = 47/77).

assessed on the basis of Grand Island, Nebraska, climatological records. The results, based on medium frame Hereford-Angus steers fed a medium energy diet over a 350-lb growth period, are given in Table 2. All values are relative to the average growth rates and feed conversions for the 15-year period. On the basis of "standard conditions," the winters can be classified in terms of impact on performance:

Above-average growth, better-than-average feed conversion:

Quite mild - 1965, 1971, 1975
Mild - 1966, 1967, 1973

Near normal growth and feed conversion:

1969, 1970, 1972, 1976

Below-average growth, worse-than-average feed conversion:

Moderately severe - 1964, 1968, 1974, 1977
Severe - 1978.

The average gain for animals maintained under "standard conditions" in hard-surfaced lots (no mud) for all years was 1.69 lb/day, with a feed conversion of 9.56 lb feed/lb gain. The best years (1965, 1971, and 1975) for growth indicated a predicted gain of 1.71 lb/day, with the least feed required in 1975 (9.44 lb feed/lb gain). The 1978-79 winter had the most extreme impact of the 15 years examined for Grand Island with growth and feed conversion of 1.66 lb/day and 9.73 lb feed/lb gain, respectively. While the differences in relative performance between the worst and best years do not seem large, they do represent a difference of six extra days to grow 350 lb and a 3 percent higher feed bill. The existence of hock-deep mud (assumed when temperatures were between 25 and 45°F) in a dirt lot for otherwise similar animals and feed indicated the average gain for all years to be reduced to 1.62 lb/day with a feed conversion of 9.98 lb feed/lb gain. The differences between worst and best years were five extra days to gain 350 lb and a 2 1/2 percent higher feed bill. Feeding a higher energy ration to animals in a dirt lot (same hock-deep mud assumption) increased the average gain for all years to 2.37 lb/day with a feed conversion of 7.06 lb feed/lb gain. The differences between worst and best years were seven extra days to gain 350 lb and a 5 percent higher feed bill. Similar analyses with large

exotic crossbred animals indicated adverse weather to have nearly twice the impact on the differences between worst and best years in the various situations evaluated for the Hereford-Angus crossbreds. For example, hock-deep mud added ten days to the feeding period for the exotic crossbreds to gain 350 lb, and required 4 3/4 percent more feed compared with the five extra days and 2 1/2 percent more feed for the Hereford-Angus crossbreds. However, the exotic crossbreds needed about 20-22 fewer total days for gaining 350 lb than did the Hereford-Angus crossbreds under comparable "standard" conditions.

Altered performance in terms of health and well-being of farm animals can also result from adverse environments. For example, gestation length and birth weights, which indirectly affect neonatal health, are significantly reduced in hot weather. Further, animal stress resulting from hot weather can result in activation of latent viruses to make a favorable environment for secondary bacterial infection, or it can result in increased intensity of a disease by impairing the immunologic function.

Performance losses of farm animals are highly dependent on the degree of acclimation (short-term adaptation). There is also a widely recognized ability of *ad lib*-fed growing animals to "catch up" (compensate) subsequent to moderate levels of nutritional stress; similar compensatory growth after thermal stress is an evident parallel. Within the limits of compensatory capabilities of growing farm animals, there is a reduced need for environmental modification. There is also some evidence of compensatory performance in lactating cows, although the likelihood of complete compensation appears small.

Behavioral patterns of farm animals are definitely altered by adverse environments as they attempt to maintain body temperature. During cold weather, they adjust posture, huddle with other animals, and usually increase feed intake. In hot weather, feeding times are altered, feed intake is reduced, water intake is increased, and heat relief measures (e.g., shade, wind) are sought. This flexibility in behavior can serve to limit performance losses and is a major contributor to the nominal losses over the broad range of temperatures noted in Figure 1. However, cattle do not always behaviorally respond in their best interest, as when they bunch in the presence of biting flies

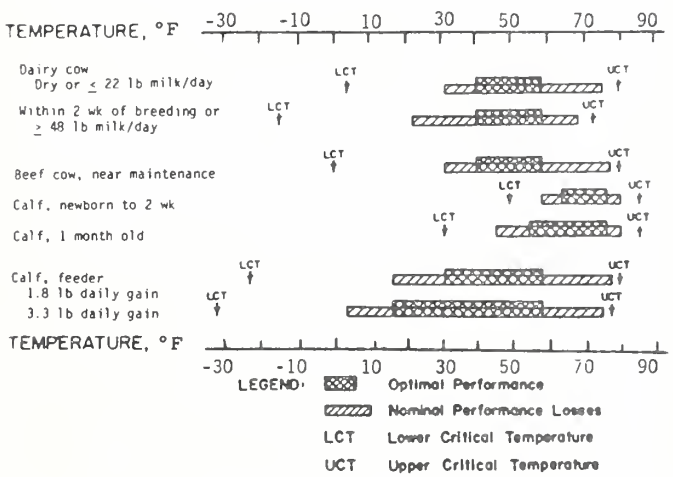

Figure 1—Critical ambient temperatures and temperature zones for optimal performance and nominal performance losses in *Bos taurus* cattle. Values shown represent the large majority of the designated population; variations in health and general physical conditions, acclimation to seasonal conditions, adequacy of feed and water, freedom from parasites and other pests, and thermal factors other than temperature can alter the response of individual animals. Wetted skin and hair, or air velocities above 1 ft/sec, shift all temperatures upward; elevated humidity or exposure to solar radiation shift all temperatures downward.

during hot weather, which may increase heat stress. Behavior also is a significant factor in limiting performance losses only to the extent that management practices permit its expression. If, for example, the animal has no access to shade in hot weather, it will not be able to reduce thermal stress resulting from solar radiation. Conversely, animals without shelter in winter will not be able to voluntarily escape thermal stress that may be imposed by wind, precipitation, or mud.

Coping with climate and weather

For weather conditions within the limits noted for optimal performance or nominal losses, there is little need for special shelter or environmental modification practices for cattle, other than newborn and very young calves. Conversely, stress-limiting protective measures can be helpful in extreme conditions to assure well-being and survival of the animals for further productive performance. Newborn calves benefit from shelter from chilling winds and precipitation during cold weather. Animals nearing market weight are particularly vulnerable to hot weather, especially during periods of high humidity. Special measures may be required during handling and transport of market animals during extreme cold or heat. A Livestock Weather Safety Index, developed by the Livestock Conservation Institute on the basis of death losses during shipping of market animals, serves as a basis for livestock advisories in hot weather. The categories, associated with the Temperature-Humidity Index as defined in Table 1 are:

THI value	*Category*
70 or less	Normal
71-78	Alert
79-83	Danger
83 or above	Emergency

Advisory forecasts of "danger" or "emergency" category conditions issued by the U.S. National Weather Service provide a basis for tactical actions, such as postponing stressful activities for animals or taking measures to limit stress (e.g., handling in early morning, wetting the animals, etc.).

The impact of sub-optimal conditions which are not life-threatening is less clear. Although we do not yet have adequate information to indicate cost-benefit ratios from the application and operation of various environmental modification practices, the rest of this section focuses on possible alternatives for consideration by cattle managers.

To effectively alter the microclimate of an animal through housing or environmental modification, we must consider altering one or more of these factors: temperature of the surrounding surfaces (e.g., by providing shades or other infrared radiation shields); air temperature (e.g., by providing auxiliary heating or cooling); air velocity (e.g., by windbreaks or augmenting natural airflow with fans); air vapor pressure (e.g., by evaporating water); radiation shape factors; conductivity of surfaces that an animal might contact; and protection from or augmenting precipitation (e.g., by shelters or sprinklers).

Open or Partially Enclosed Shelters: Providing animals with adequate opportunity for behavioral thermoregulation (access to shades, walled enclosures, and other relatively passive alternatives) should receive first consideration, as such responses are complementary to physiological regulation and require minimal energy use. Cattle have minimal shelter requirements at most life stages, as noted in Figure 1; an exception is the newborn calf, particularly in cold, wet weather.

a. *Hot conditions*: Shades and other minimal measures should be thought of as a form of insurance for protecting farm animals in hot climates. The most effective shades are trees, as they provide protection from sunlight combined with the radiation

sink effect created by the relatively cool leaves as a result of evaporating moisture. However, trees are not always available for livestock shades. Hay or straw shades are the most effective artificial shade materials; solid shade provided by sheet metal painted white on top is the next most effective. Slats or other shade materials with less than total shading capabilities are considerably less effective; for example, slatted snow-fencing with approximately 50 percent openings is only 59 percent as effective as new aluminum sheeting for shading animals.

Shades should be 12 to 14 ft high in areas with clear, sunny afternoons to permit maximum exposure to the relatively cool north sky, which acts as a radiation sink. However, in areas with cloudy afternoons, shades of 7 to 9 ft in height are more effective, as they limit the diffuse sky radiation received by animals beneath the shades. The amount of shade area needed for young cattle is 7-1/2 to 13 ft^2/head while larger cattle need at least 20 to 40 ft^2/head.

Partially enclosed shelters can further reduce the thermal radiation received by animals. Under clear-sky conditions, the average radiant heat load over a 7-h period was reduced almost 10 percent by the addition of a west wall to a simple shade. Adding more walls helped, but to a lesser degree.

Negative aspects of partially enclosed structures must be considered, such as decreased natural air velocity and sanitation. The use of wire or cable in shelters or open penning minimizes restrictions to air flow and permits maximum convective cooling. There are no guidelines for evaluating the benefits of open *vs* partially enclosed shelters, as the relative merits are dependent on many factors.

For installations subject to both hot and cold weather, open-front structures facing to the south with large doors or panels in the north wall are an acceptable compromise. Use of fans in hot weather should be considered if natural air velocity is less than about 7 ft/sec; however, increasing air velocity above 8 ft/sec adds little additional benefit.

b. *Cold conditions*: Exposure to cold, especially when combined with wind and precipitation as noted in the caption for Figure 1, can result in thermal demands which exceed an unprotected animal's homeostatic and metabolic capacity. Windbreaks and partially enclosed shelters for vulnerable animals in cold climates should, as with shades in hot conditions, be considered as a form of insurance. Depending on the specifics of design, windbreaks can provide effective downwind protection as far as 10-15 times their height. Windbreaks designed with 20-25 percent opening are more effective than solid barriers; an evergreen tree stand can be particularly effective, if available. Partially enclosed structures open to the south are preferred to permit warming of sheltered animals by solar radiation from the low winter sun angles.

Enclosed Shelters: Open or partially enclosed shelters are only effective to the extent that animals elect to use them; thermal comfort is not always an animal's highest priority in elective situations. Livestock managers often prefer to exert some control over the thermal environment of their animals by using enclosed structures. The degree of control ranges from naturally ventilated buildings operated as cold housing in winter and open shelters in summer, to insulated buildings operated to maintain a minimum of temperature variation year-round by means of tightly controlled ventilation and supplemental heating and/or cooling.

To the extent that enclosed shelters are capable of providing enhanced animal performance and well-being and are operated to realize that capability, they are an alternative for consideration in the decision-making process. However, it should be noted that both initial and operating costs go up much more rapidly than the derived benefits as the temperature is more closely controlled.

Other Alternatives

a. *Hot conditions*: In addition to adequate cool water for drinking, water can be an effective cooling agent. Cooling is obtained directly through wetting of the animal's surface and subsequent evaporation, or through indirect evaporative cooling of air which is used, in turn, to cool the animal. Cooling of hot surrounding surfaces can also reduce the radiation heat load on animals. Although the effectiveness of evaporating water is lessened by periods of high humidity, peak daily temperatures usually occur during mid-afternoon in the summer, when relative humidity is lowest.

Using water for direct wetting of the animals is an effective emergency measure. As a routine protective practice, wetting can be efficiently accomplished by sprinkler nozzles with a capacity of 2.5 to 5 gal/h and controlled by a timer to provide 5-10 min of spray out of each 20-30 min. Fogger nozzles, often mistakenly recommended for wetting animals, form fine droplets which cling to the animal's outer hair coat; sprinkler nozzles which wet the skin are more effective. Performance benefits from the use of direct wetting as a means of improved heat dissipation are still not confirmed, as some studies with cattle have shown measurable benefits but others have not. Increased air flow over wetted animals enhances the effectiveness of direct wetting, especially at low natural air velocities.

Evaporative coolers specifically designed to reduce air temperatures in livestock shelters can be quite effective. Use of evaporative cooling has expanded rapidly in hot climates because of its relatively simple design and favorable benefit:cost ratio. A correctly designed evaporative cooler will reduce the dry-bulb temperature of outside air entering the cooler by 80 percent of the wet-bulb depression. Table 3 provides an analysis of temperatures obtainable by evaporative cooling at various locations, which indicates that air temperatures of 85°F or less can normally be attained in all regions of the U.S.

b. *Cold conditions*: Use of supplemental heating is usually restricted to newborn or very young calves, particularly during cold, wet weather. Straw bedding can reduce heating requirements, and it should always be kept in mind that the immediate surroundings of the animal are primarily what influence heat loss. Providing heating for a localized area will often meet the animals' needs without undue heating costs. Radiant heaters, floor heating, or small warm-air ducts are practical means of local heating.

Table 3.—For correctly designed evaporative coolers[a], the number of days in a normal summer season (June 1 to Sept. 3) for which the maximum dry-bulb temperature equals or exceeds:

	Temperature, °F							
Station	80	81	82	83	84	85	86	87
Atlanta, GA	9	3	1					
Barbers Point, HI	0							
Beeville, TX	57	32	12	6	1			
Boise, ID	17	7	3					
Cheyenne, WY	22	13	6	2	1			
Columbia, MO	17	10	4	2				
Dallas, TX	52	33	15	6	1			
Dayton, OH	8	5	2	1				
Harrisburg, PA	2	1						
Lone Rock, WI	7	5	3	1				
Massena, NY	2	1	1					
Memphis, TN	38	30	15	8	4	2	1	
Oklahoma City, OK	16	7	3	1				
Phoenix, AZ	29	14	5	2	1			
Sacramento, CA	3	1	1					
Sioux Falls, SD	6	3	1					

[a]Eighty percent of wet-bulb depression assumed. Temperatures within enclosed evaporatively cooled livestock structures would normally be within 2-3°F of air leaving the fully wetted cooler pad.

Summary

Short-term weather disturbances can alter the physiological state of cattle. In terms of performance, however, cattle are relatively insensitive to moderate and cool weather and climates. Heat or extreme cold can cause adverse effects, especially when combined with compounding factors (e.g., precipitation and wind or poor nutrition in cold or high humidity in heat). Newborn calves, market-weight cattle, and breeding animals are most vulnerable to adverse weather conditions. This report summarizes some recent research observations and ways of coping with adverse conditions which can improve the management of cattle. Alternatives available to individual livestock managers should be considered and selections made on the most rational basis possible (e.g., cost:benefit ratio, animal health); not all are profitable or acceptable in all situations. Environments established for maximum performance or efficiency of feed energy utilization are not necessarily optimal. The point cannot be emphasized too strongly that rational agricultural management must be based on valid information about the biological and production systems. Evaluation of the consequences which result from various alternatives logically involves economics and risks, but should also consider animal well-being, availability of resources, proven technological feasibility, and managerial capabilities.

Methane From Beef Cattle Manure and Straw Mixtures

Andrew G. Hashimoto and Steven A. Robinson[1]

Introduction

The major barrier to wide application of anaerobic fermentation technology in the agricultural sector is economics. Research and development efforts in anaerobic fermentation technology have shown that methane can be produced from livestock manures but that economies-of-scale have a significant impact on the economic feasibility.

Farmer-constructed and -operated systems were estimated to be economically feasible for beef feedlots between 1,000 to 2,000 head, and commercial "turn-key" systems were feasible for feedlots larger than 8,000 head. However, since the average U.S. beef feedlot capacity is about 150 head, and less than three percent have capacities greater than 1,000 head, this means that only large feedlots would benefit from this technology. This is true for other species as well; that is, methane production is economically feasible only for larger-than-average sized livestock enterprises.

By combining crop residues with manure, smaller livestock enterprises may be able to produce methane at a lower unit cost because of the larger plant size. Another advantage of combining crop residues with manures is the large amount of crop residue in close proximity to livestock enterprises. In the U.S., about 200 million tons (dry weight basis) of collectable corn stalk and wheat straw could be available for fermentation, as opposed to about 30 million tons of collectable manure. Thus, there is at least seven times more crop residue than manure for fermentation. A third advantage of mixing crop residue with manure is that, nutritionally, the highly nitrogenous manure complements the highly carbonaceous but nitrogen-deficient crop residue.

There are, however, several problems associated with fermenting crop residue. The major problems are the relatively low biodegradability of untreated residue, the cost and possible adverse side-reactions of pretreating crop residues, the increased materials-handling problems associated with mixing and transporting manure-crop residue mixtures, and the long-term agronomic consequences of removing large amounts of crop residue from productive crop land.

The "dry fermentation" system proposed by researchers at Cornell University has several advantages for fermenting crop residue. In essence, the system is a batch fermentation of crop residue at moisture contents between 75 to 85 percent. Advantages of this system are: simple "hole-in-the-ground" design; no need for size reduction or mechanical mixing of the residue; and the residue remaining after fermentation can be applied back on the land as mulch. Disadvantages of the system are: the high buffer requirement to maintain a neutral pH; the large volume of "seed" required to innoculate the fermentor; and the slow reaction rate in the fermentor.

This report describes a two-stage fermentation system that allows rapid conversion of easily degraded compounds to methane and long-term fermentation for more slowly degraded compounds. The advantages of this system are: thermo-chemical pretreatment or size reduction of the straw are not required; the straw is handled only at the beginning and end of fermentation (i.e., materials handling problems associated with mixing and pumping straw slurries are minimized); and the system will selectively ferment the easily and less degradable compounds. This report also describes studies evaluating whether anhydrous ammonia treatment can increase the methane yield of straw.

[1]Hashimoto is the research leader, and Robinson is an operations assistant, Agricultural Engineering Unit, MARC.

Procedure

The first stage of the two-stage system was a high-rate fermentor (HRF) with a working volume of 175 ft³. It was insulated with 1 in of polyurethane foam. Four baffles were equally spaced around the inside of the tank. The HRF was mixed with a variable-speed mixer and two, three-blade, stainless-steel marine propellers on a stainless-steel shaft. An external double-tube heat exchanger was used to maintain a 130°F fermentation temperature using hot water heated to 150°F. The HRF was operated at 5-days' retention time and influent volatile solids concentration of about 8 percent volatile solids (VS) for Trial 1 and the first portion of Trial 2. In the second portion of Trial 2, the HRF was operated at 10-days' retention time and 5 percent VS.

The second-stage straw fermentor (SF) was a 600-gal steel tank insulated with 3 in of polyurethane foam. The working volume of the tank was 500 gal. An expanded steel screen was placed 1 ft above the floor of the tank to support the straw and to prevent plugging of the outlet. Another screen was placed 11.5 ft above the lower screen to prevent floating straw from plugging the gas outlet pipe. Influent slurries entered through a 3 in pipe at the top of the tank, while effluent drained from the bottom of the tank. The biogas produced was collected at the top of the tank and passed through a temperature-compensated gas meter and a pressure-relief valve. The temperature was monitored using three thermocouples at the top, middle, and near the bottom of the working volume. The SF temperature was an average of these three readings. The SF temperature was maintained at about 95°F using external heat exchangers.

The manure (1-10 days old) used in this study was gathered from steers housed on partially roofed, concrete-floored pens. The steers weighed from 750 to 1,250 lb. Their ration consisted of 85 percent yellow corn, 13 percent corn silage, 1.6 percent soybean meal, 0.2 percent limestone, 0.1 percent each of dicalcium phosphate and salt, and trace minerals and vitamins A, D, and E. The ration was antibiotic-free. The manure was transported by a small front-end loader and dumped into a mixing-degritting tank, diluted to 10-12 percent VS, and mixed with a 1-hp variable speed mixer.

Wheat straw, from hard-winter wheat (Bennett) grown in Clay County, Nebraska, was baled in large round bales (approximately 900 lb) and stored in an open-front barn.

Trial 1. The SF was loaded with 1,055 lb of straw. From day 1 to 11 and on day 13, 35 ft³ of HRF effluent was pumped into the SF in order to fill the SF. From day 9, the liquid from the SF was pumped through the heat exchanger to maintain the average SF temperature of 95°F. On days 22 through 29, cold weather and storm-related power failures caused the average tank temperature to fall below 86°F. On day 29, an additional 35 ft³ of HRF effluent was added to the SF to replace the volume removed for sampling. The straw was fermented for 70 days; then the SF was drained and injected with 68 lb of anhydrous ammonia. Beginning on day 88, 35 ft³ of HRF effluent was added each day for 12 days. Trial 1 was completed on day 123. The volumetric methane production rate of the HRF averaged 4.2 ft³ methane/ft³ fermentor volume/day when the SF was being filled.

Trial 2. The SF was loaded with 1,060 lb straw. From day 1 to day 11, 35 ft³ of HRF effluent was pumped into the SF each day. The SF temperature was maintained at 95°F, and the straw was fermented for 79 days. The SF was drained, and 68 lb of anhydrous ammonia was pumped into the SF on days 88 and 89. Between days 90 to 100, 18 ft³ per day of HRF effluent was pumped into the SF. Trial 2 was terminated on day 135.

System performance. Table 1 shows the analyses of the influent to the HRF, the influent to the SF (which was also the effluent from the HRF), and the effluent from the SF. There was little difference in constituent concentrations of the influents and effluents before and after anhydrous ammonia treatment in Trial 1, and between the constituent concentrations in Trial 1 and the concentrations before anhydrous ammonia treatment in Trial 2. The lower constituent concentrations in Trial 2 after anhydrous ammonia treatment reflect the higher HRT and lower influent concentration used in that portion of Trial 2.

In Trial 1, 6,210 ft^3 of methane was produced in the first 79 days. Of this total, the HRF effluent contributed about 2,540 ft^3 (estimated by 108-day batch fermentations). Thus, the methane yield from the straw in Trial 1 was 4.3 ft^3 CH_4/lb VS. The methane produced after ammonia injection was 1,750 ft^3, and the contribution from the HRF effluent was calculated to be 2,065 ft^3. Thus, no additional methane was produced after ammonia injection. The total methane yield from both phases was 4.3 ft^3 CH_4/lb VS.

In Trial 2, 4,480 ft^3 of methane was produced during the first 79 days with the HRF effluent contributing 1,640 ft^3. The methane yield was calculated to be 3.4 ft^3 CH_4/lb VS. After anhydrous ammonia injection, an additional 0.3 ft^3 CH_4/lb VS was produced. The total methane yield from both phases was 3.7 ft^3 CH_4/lb VS.

It is unlikely that the anhydrous ammonia injection was responsible for increasing the methane yield. The methane production rates after anhydrous ammonia injection were 17 and 28 ft^3 CH_4/day for Trials 1 and 2, respectively. These rates are comparable to the methane production rates just before anhydrous ammonia was injected into the straw.

Results

The mean methane yield from Trials 1 and 2 was 4 ft^3 CH_4/lb VS, with a mean standard error of 0.3 ft^3 CH_4/lb VS. When samples from the same cutting of straw were ball milled and then fermented for over 100 days in laboratory batch fermentors, the mean methane yield from ten replicates was 4.8 $\pm$ 0.2 ft^3 CH_4/lb VS. Thus, the methane yield from the pilot-scale system was 83 percent of the yield obtained in the laboratory. The lower yield was probably caused by incomplete fermentation of the straw in the center of the packed straw. This was verified by visual observation of the straw on the edge compared to the center of the straw fermentor. The straw at the top, bottom, and sides of the fermentor was dark and decomposed, while the straw at the center looked undigested. These results indicate that large-scale systems must be designed to uniformly distribute the HRF effluent in order to achieve a more uniform and complete straw fermentation.

The pilot-scale system was originally designed to allow leaching of soluble substrate from the straw, then fermentation to methane in the HRF. We anticipated that much higher levels of volatile fatty acids would be produced in the SF and that this would inhibit methanogenesis. This study showed that methanogenesis was easily established and maintained in the SF. This may have happened because of the relatively large amount of inoculum used (455 ft^3) in proportion to the amount of straw fermented (1,035 lb). In full-scale systems where the inoculum:substrate ratio may not be as favorable as in this study, leachate recycle back to the HRF may be necessary to convert the accumulated volatile fatty acids. If this is necessary, it would seem logical to use the recycled leachate to dilute the manure for the HRF. However, based on other results, inhibition occurs when the leachate is used as the sole source make-up water. Thus, our recommendation is to not use more than one-half of the leachate as make-up water.

Anhydrous ammonia was injected into the SF to evaluate whether this would be an economical full-scale method to increase the methane yield from straw. The ideal experimental design would have at least two systems fermenting untreated straw and at least two other systems fermenting the ammonia-pretreated straw. However, since only one pilot-scale system was available, we felt that the most appropriate procedure to evaluate the effect of ammonia pretreatment was to ferment the untreated straw before pretreatment. The results showed little, if any, effect of ammonia pretreatment on methane yield. In comparison, laboratory batch fermentation of ammonia-pretreated straw samples from the same cutting indicated between 11 to 14 percent increase in methane yield.

The different pretreatment conditions may explain some of the variation in effect on methane yield; however, the more likely explanation is that the procedures used to calculate the mass balances of the pilot-scale system were not capable of detecting methane yield differences on the order of 10 to 15 percent. In any case, it is not likely that a 10 to 15 percent increase in methane yield would be sufficient to offset the additional ammonia pretreatment costs for materials, labor, and facilities.

Economic assessment of this two-stage system indicated that a straw-cost of slightly over $15/ton was the break-even cost, above which the investment opportunity decreased as the straw-content increased. This straw cost is close to the cost associated with harvesting the straw. These results show that straw costs greater than $15/ton would tend to decrease the proportion of straw to manure to be processed, while straw costs of $15/ton or lower would tend to increase the proportion of straw. However, there is a maximum proportion of straw above which the SF will not operate properly. Obviously, inoculum and nutrients other than carbon must be provided to initiate and sustain the fermentation of straw. Maximum recommended proportions of straw would be between 80 to 90 percent of the average daily feedstock loading rate.

The straw compaction density had a significant effect on the overall economics of the two-phase system. The initial straw compaction density in this study was 2.3 lb/ft^3. Higher densities were not achieved because the shape of the SF allowed only manual filling and compaction of the straw. Compaction densities up to 41 lb/ft^3 can be achieved in sanitary landfills; however, fermentation at these high densities and resulting low moisture contents is generally inhibited. Other researchers have found that a minimum moisture content of 70 percent was needed to ferment 90 percent of the biodegradable VS of crop residue at compaction densities between 17 and 23 lb/ft^3 in one year.

For a plant designed with a straw compaction density of 12 lb/ft^3, minimum moisture content of 70 percent, 80 percent straw content, 35 percent income tax bracket, and straw cost of $15/ton, the farm size necessary to achieve a discounted cash flow rate of return (DCFRR) of 15 percent was estimated to be 2,200 acres of straw and a 930-head feedlot. To put this size into perspective, there were 1,935 feedlots of 1,000-head capacity or larger in 1982. In order to attain a DCFRR of 15 percent, the beef-cattle feedlot size for an anaerobic fermentation system using only manure is approximately 2,800 head. Thus, fermenting straw along with cattle manure does enhance the economics of the system, allowing the economically feasible feedlot size to be about one-third the size as when only manure is used.

Table 1.—Analyses of influents and effluents of high rate fermentor (HRF) and straw fermentor (SF) during trials 1 and 2[a]

	HRF Influent		SF Influent		SF Effluent	
	H	HA[b]	K	KA[b]	KS	KSA[b]
Trial 1						
Total Solids	92.2>9.6	90.2>4.0	54.6>1.9	49.1>1.3	36.6>0.72	38.0>6.1
Volatile Solids	78.4>9.3	77.3>4.0	42.5>1.5	37.2>9.1	24.9>6.3	24.9>3.8
Alkalinity	4.91>0.55	3.63>0.42	10.8>0.4	9.29>0.40	13.4>1.5	14.7>0.8
Total Volatile Acids	7.95	6.47>1.29	1.50>0.08	0.54>0.04	0.64>0.38	0.52>0.19
Ammonia-N	1.02	0.84	1.84>0.04	1.32	2.26>0.32	2.79>0.21
Total Kjeldahl-N	3.84>0.18	3.39	3.86>0.10	3.21	3.61>0.13	3.83>0.10
pH	5.33>0.45	4.64>0.18	7.90>0.05	7.83>0.04	7.61>0.1	7.77>0.16
Trial 2						
Total Solids	92.8>5.6	56.8>6.3	45.8>1.2	26.3>2.0	33.9>1.3	18.0>5.5
Volatile Solids	81.0>4.8	49.5>5.8	35.3>0.8	19.9>1.3	22.4>8.9	13.1>4.9
Alkalinity	3.46>0.32	1.72>0.46	8.87>0.32	6.44>0.68	12.0>1.2	10.4>1.9
Total Volatile Acids	9.06>1.34	5.34>0.81	0.64>0.02	0.25>0.08	0.31>0.05	2.43>0.46
Ammonia-N	0.84>0.04	NA[c]	1.25>0.02	NA[c]	1.89>0.14	3.08>0.02
Total Kjeldahl-N	3.23	NA[c]	NA[c]	NA[c]	3.01>0.30	3.15>0.47
pH	4.60>0.18	4.46>0.21	7.74>0.07	7.64>0.19	7.79>0.11	8.25>0.57

[a]Expressed as mean > standard deviation, units are g/l except pH.
[b]A denotes analyses after anhydrous ammonia treatment
[c]NA = not analyzed.

Notes

Notes

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